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Water Allocation Model

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Abbreviations and Acronyms

A	AFRP	Anadromous Fish Restoration Program
	ANN	Artificial Neural Network
B	Bay-Delta Plan	Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary
	BDCP	Bay Delta Conservation Plan
	BiOp	Biological Opinion
	BoM	Beginning-of-month
C	CA	California Aqueduct
	CaSIL	California Spatial Information Library
	CCTL	Central Coast and Tulare basin
	CDEC	California Data Exchange Center
	CDFW	California Department of Fish and Wildlife, formerly Department of Fish and Game
	cfs	cubic feet per second
	CIMIS	California Irrigation Management Information System
	CM	canal mile
	COA	Coordinated Operations Agreement
	CSD	Community Service District
	CSA	Community Service Area
	csv	comma-separated values
	CUP	Consumptive Use Program
	CVP	Central Valley Project
	CVPA	Central Valley Planning Area model
	CVPIA	Central Valley Project Improvement Act
	CWD	Community Water District
D	DAU	Detailed Analysis Unit
	DETAW	Delta Evapotranspiration of Applied Water
	DI	Demand Index
	DLL	Dynamic-Link Library
	DMC	Delta-Mendota Canal
	DSIWM	Division of Statewide Integrated Water Management, Department of Water Resources
	DSM2	Delta Simulation Model 2
	DU	Demand Unit
	DWR	California Department of Water Resources
	DXC	Delta Cross Channel
E	EBMUD	East Bay Municipal Utility District
	EROS	Earth Resources Observation and Science
	ET	evapotranspiration
	eWRIMS	Electronic Water Rights Information Management System
F	FAO	Food and Agricultural Organization
	FC&WCD	Flood Control and Water Conservation District
	FERC	Federal Energy Regulatory Commission
	FMS	Flow Management Standard
	FNF	full natural flow
	FRI	Four Reservoir Index
	FRSA	Feather River Service Area
G	GIS	geographic information system
H	H&S	Health and Safety
	HOR	Head of the Old River
	HUC	hydrologic unit code
I	IBU	in-basin use
	ICA	irrigated crop acreage

	IDC	Irrigation and Drainage Company
	IFII	Impaired Folsom Inflow Index
	IFR	instream flow requirement
J	JSA	Joint Settlement Agreement
L	LP	linear programming
M	M&I	Municipal and Industrial
	MAF	million acre-feet
	MFR	Minimum Flow Requirement
	mgd	million gallons per day
	MILP	Mixed Integer Linear Programming
	MOA	memorandum of agreement
	MRDO	minimum required Delta outflow
	MWC	Mutual Water Company
N	NASA	National Aeronautics and Space Administration
	NDOI	Net Delta Outflow Index
	NED	National Elevation Dataset
	NHD	National Hydrography Dataset
	NLCD	National Land Cover Database
	NMFS	National Marine Fisheries Service
	NOD	north of Delta
	NRCS	Natural Resources Conservation Service
	NTU	nephelometric turbidity unit
	NWR	National Wildlife Refuge
O	OCAP	Operation Criteria and Plan
	OMR	Old and Middle River
P	PAE	potential application efficiency
	PEST	parameter estimation
	PG&E	Pacific Gas and Electric
	PUD	Public Utility District
	PWSS	Public Water System Statistics
R	Reclamation	U.S. Department of the Interior, Bureau of Reclamation
	RM	river mile
	RMSE	root mean square error
	RPA	Reasonable and Prudent Alternative
S	SacWAM	Sacramento Valley Water Allocation Model
	SBA	South Bay Aqueduct
	SCS	Soil Conservation Service
	SEI	Stockholm Environment Institute
	SIMETAW	Simulation of Evapotranspiration of Applied Water
	SMUD	Sacramento Municipal Utility District
	SOD	south of Delta
	SR	surface runoff and return
	SRI	Sacramento River Index
	SWP	California State Water Project
	SWRCB	State Water Resources Control Board
T	TAF	thousand acre-feet
	TUCP	Temporary Urgent Change Petition
U	UDC	user-defined constraint
	USACE	U.S. Army Corps of Engineers
	USFWS	U.S. Fish and Wildlife Service
	USGS	U.S. Geological Survey
	UWFE	unstored water available for export

	UWMP	Urban Water Management Plan
W	WA	Water Agency
	WBA	Water Budget Area
	WCD	Water Conservation District
	WD	Water District
	WEAP	Water Evaluation and Planning system
	WMA	Wildlife Management Area
	WPCF	Water Pollution Control Facility
	WPCP	Water Pollution Control Plant
	WSI	Water Supply Index
	WTP	Water Treatment Plant
	WUA	Water Users Association
	WWTP	Wastewater Treatment Plant
	WYT	water year type
X	X2	Location of the 2 parts per thousand salinity contour (isohaline), one meter above the bottom of the estuary, as measured in kilometers upstream from the Golden Gate Bridge

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Chapter 1 Overview

1.1 Introduction

In 2013, the Stockholm Environment Institute (SEI) contracted with the State Water Resources Control Board (State Water Board) through ICF International to develop a Water Evaluation and Planning system (WEAP) model for use in the update of the 2006 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (Bay-Delta Plan). The State Water Board's water quality control planning process for approving amendments to the Bay-Delta Plan must ensure the reasonable protection of beneficial uses, which requires balancing competing beneficial uses of water, including municipal and industrial (M&I) uses, agricultural uses, fish and wildlife, and other environmental uses. The State Water Board's process will include an analysis of the effects of any changed flow objectives on the environment in the watersheds in which Delta flows originate, in the Delta, and in the areas in which Delta water is used. It will also include an analysis of the economic impacts that could result from changed flow objectives. This report describes the development of the Sacramento Valley Water Allocation Model (SacWAM) model that will be used to support the State Water Board's efforts.

The SacWAM domain is shown in Figure 1-1. The model represents the Sacramento River Hydrologic Region, the Trinity River watershed above the Lewiston gauge (USGS 11525500), and the northern part of the San Joaquin River Hydrologic Region downstream from the gauge at Vernalis (USGS 11303500). The model includes the entire Sacramento-San Joaquin Delta (Delta), and the Delta Eastside streams comprising the Cosumnes, Mokelumne, and Calaveras rivers. SacWAM also includes the Delta-Mendota Canal (DMC), California Aqueduct, and San Luis Reservoir. Flows in the San Joaquin River at Vernalis are specified based on previous modeling efforts developed during the Phase I update of the Bay-Delta Plan. SacWAM represents the water resources within the model domain using a comprehensive approach in which hydrology, water infrastructure, and water management are all contained within the simulation model.

The model was constructed to satisfy specific needs of the State Water Board as it develops an updated Bay-Delta Plan. Model requirements include:

- Period of simulation comprising water years 1922 – 2009.
- A monthly time step.[1]
- Simulation of unimpaired flows in the mountain and foothill watersheds that surround the valley floor.
- Simulation of stream flows at the confluences of tributaries to the Sacramento River.
- Simulation of stream flows at United States Geological Survey (USGS) and California Department of Water Resources (DWR) gauges located on the Sacramento River.
- Simulation of Delta inflow, net Delta outflow, and flows within the south Delta.
- Ability to simulate unimpaired flows.
- Simulation of major water infrastructure and their operations in the upper watersheds.

[1] Crop water demands and rainfall-runoff are determined using a daily time step.

- Simulation of water allocations and diversions on the valley floor.

By necessity, SacWAM simplifies the depiction of stream flows by aggregating surface water diversions, return flows, and groundwater inflows to the stream network. Figure 1-2 and Figure 1-3 show the specific points of interest to the State Water Board where flow is accurately simulated in SacWAM, despite these simplifications.

In the upper watersheds, natural hydrological processes including snow accumulation and melt, rainfall runoff, native vegetation evapotranspiration, and groundwater processes are represented using the Soil Moisture Model of the WEAP software. The Soil Moisture Model was calibrated to unimpaired flows measured or calculated at the edge of the valley floor. All reservoirs with storage of greater than 100,000 acre-feet and all inter-basin transfers exceeding 15,000 acre-feet/year are represented. Typically, these storage and transfer operations are simulated using average monthly historical values of storage and flow. In contrast, foothill reservoir operations including Trinity, Whiskeytown, Shasta, Oroville, and Folsom are simulated to meet flood control, water supply, and environmental water requirements.

Model representation of the valley floor is much more detailed than that for the upper watersheds and includes all major water diversions, canals, weirs, and flood bypasses. Agricultural water demands are represented using 20 crop types and the average irrigated acreage for 1998 – 2007. Crop water use is calculated using a daily dual crop coefficient approach (Allen et al., 1998). Urban water demands, divided into indoor and outdoor water use, are based on historical purveyor data for 2006 – 2010 for major cities and towns and on population data for smaller communities. Wildlife refuges represent permanently and seasonally flooded lands. Associated water demands are calculated in a manner similar to agricultural lands.

Operations of the federal Central Valley Project (CVP) and State Water Project (SWP) significantly affect river and channel flows within much of the model domain. Aspects of the CVP and SWP operations simulated in SacWAM include, but are not limited to:

1. Instream flow requirements (IFRs) on the Trinity, Sacramento, Feather, and American rivers[2]
2. Water Right Decision 1641 (D-1641) Delta flow requirements and Delta export restrictions
3. D-1641 water quality requirements
4. National Marine Fisheries Service (NMFS) Biological Opinions (BiOps)
5. U.S. Fish and Wildlife Service (USFWS) BiOps
6. CVP-SWP Coordinated Operations Agreement (COA)
7. CVP and SWP contract amounts and allocations

Additionally, SacWAM includes regulatory requirements, such as IFRs, that affect local reservoir operations and surface water diversions.

[2] Instream flow requirements modeled include both explicit flow requirements and approximate flows that may be needed to achieve cold water habitat water temperature targets downstream of reservoirs.

Figure 1-1. Sacramento Valley Water Allocation Model Domain

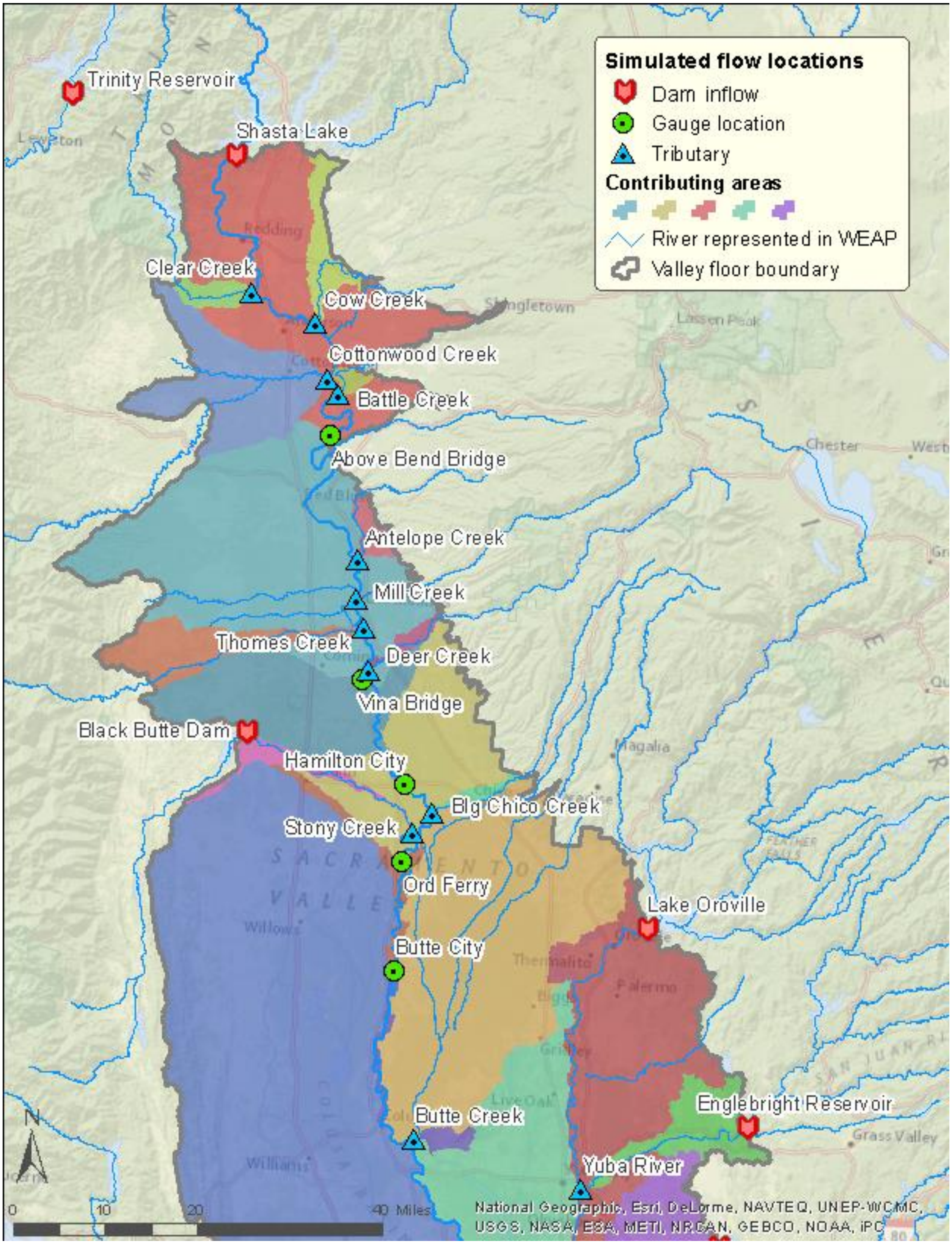

Figure 1-2. Simulated Flow Locations (North)

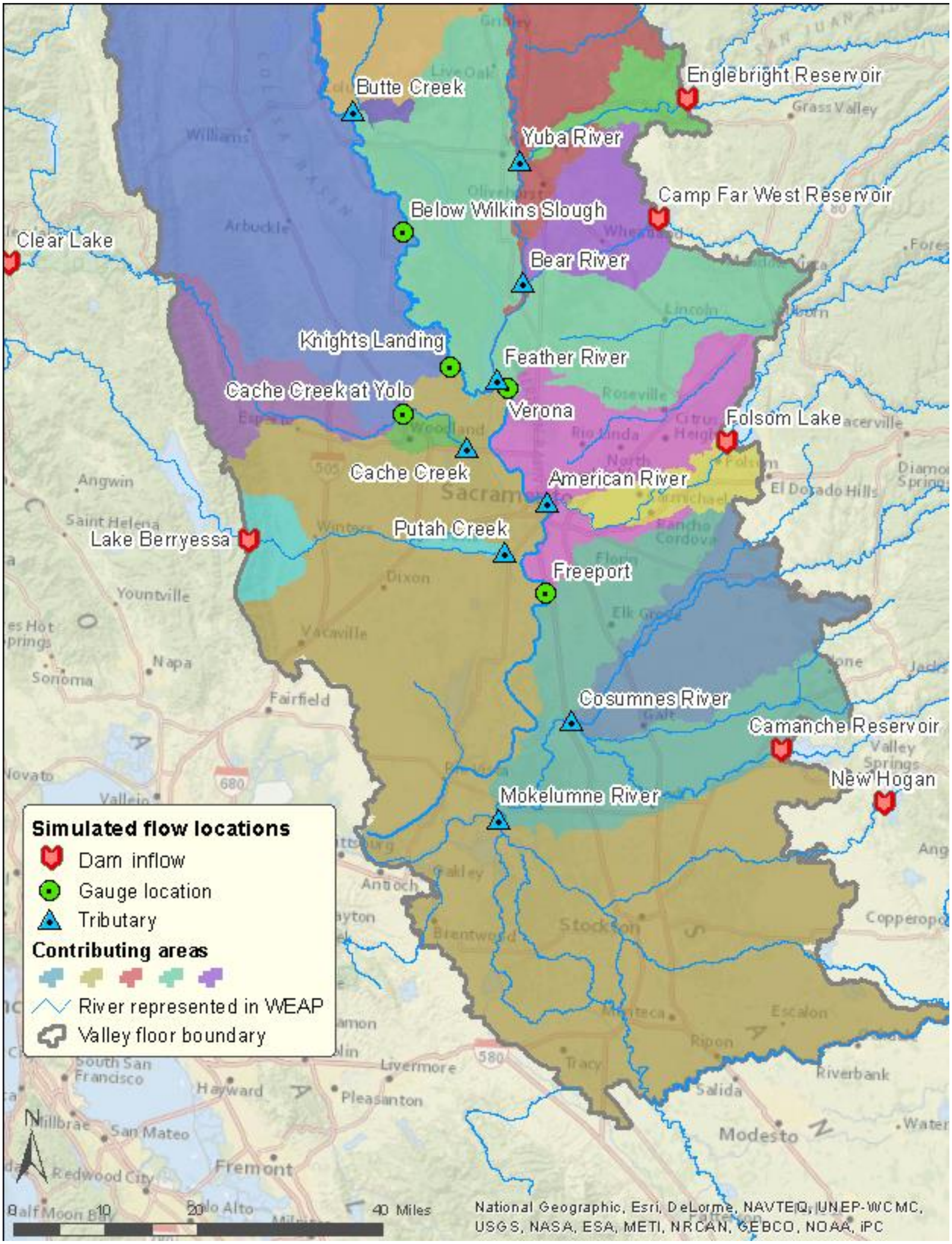

Figure 1-3. Simulated Flow Locations (South)

1.2 Organization and Contents of this Document

This report describes the methods and assumptions used to develop the SacWAM application within the WEAP software that are primarily contained in WEAP's 'Data View'. After the first three introductory chapters, chapter titles correspond to the six major categories found in the Data View in the WEAP software, and chapter subsection titles match the "branch" names used in WEAP. This organizational structure simplifies finding relevant information as a model user navigates through SacWAM. Chapters include information on the representation of the valley floor demands and hydrology, the upper watersheds, and the operations rules for the water management infrastructure. The contents of each chapter are as follows:

Chapter 1, Overview, provides general background on SacWAM and this document.

Chapter 2, Water Evaluation and Planning System, describes the WEAP software used to develop SacWAM.

Chapter 3, Schematic, describes development of the SacWAM schematic, constructed using WEAP's internal water resources objects.

Chapter 4, Demand Sites and Catchments – Delta and Valley Floor, explains the aggregation of water users into demand units, and describes simulation of water demands and water use, and model calibration for the valley floor domain.

Chapter 5, Demand Sites and Catchments – Upper Watersheds, describes the representation of the mountain and foothill watersheds that surround the valley floor, and the calibration of WEAP's internal hydrology model to simulate climate-driven snow accumulation and melt and rainfall-runoff processes.

Chapter 6, Supply and Resources, describes the parameterization of SacWAM's water resources objects using built-in object properties.

Chapter 7, Other Assumptions, describes user-defined state variables whose values are determined at the beginning of each time step and that determine technical coefficients or right-hand side resource constraints in the formulation of linear constraints on model simulation.

Chapter 8, User-Defined Linear Programming Constraints, describes complex operating rules that are formulated using arithmetic expressions rather than constraints that are automatically developed by WEAP from properties of the built-in water resources objects.

Chapter 9, Key Assumptions, lists model settings that control the mode of simulation.

Chapter 10, **Model Calibration**, summarizes the calibration of runoff from catchment objects and stream-groundwater interactions and refers readers to Appendicies A and B for more detailed discussions of the calibration.

Chapter 11, Model Use and Limitations, discusses appropriate use of SacWAM, lists current model limitations, and makes recommendations for using and interpreting model results.

Chapter 12, presents sources cited in this report.

Appendix A, Upper Watershed Hydrology Calibration, discusses the techniques used and results for the calibration of the WEAP catchment objects in the watersheds upstream of the valley rim reservoirs.

Appendix B, Sacramento Valley Floor and Delta Calibration, discusses the calibration of various aspects of the hydrological system on the Sacramento Valley floor. Validation results of CVP and SWP project operations are also presented.

As described above, parameterization of the model is documented in sections of Chapter 4 through Chapter 9 using the same headings found in the WEAP software data tree. For example, if there is a question about the Maximum Flow Volume on a transmission link on the valley floor, a description of how this parameter was derived can be found by navigating through the table of contents to the valley floor parameterization section (Chapter 4) and then following the headings as seen in the WEAP data tree *(Supply and Resources\Transmission links\Linking Rules\Maximum Flow Volume*). Phrases in *italics* in the documentation are model parameters and branches with sub-branches separated by a backslash ("\"). File pathways in the model and documentation directories also use backslashes but are not in italics.

Data and information used to develop SacWAM is contained in a directory structure on a DVD that can be provided upon request from the State Water Board. These data and information include:

- Geographic Information System (GIS) data: used to develop the schematic and define watershed parameters (4 GB)
- Climate data: used to populate WEAP's watershed objects (3 GB)
- Spreadsheets: contain reservoir storage capacity, groundwater, surface streamflow, urban, and agricultural data used to develop the hydrology and water demand parameters (135 MB)
- References: pdf copies of data references, primarily water demand data (2 GB)

These data and information are referenced in the document using three methods. The first method is the inclusion of 'File Location Information' tables found throughout the document. The second method is through standard referencing techniques; supporting documents, journal articles, and reports are cited in the text. Data sources are provided in digital form within the directory structure under 'References' except for data sources that are readily available on the internet (typically government-sponsored data repositories) that are simply referenced by their web page address. The third reference method is for supporting GIS or spreadsheet-based data. This type of data is referenced in the text using an alias in **bold** font. These aliases or referenced names are then listed in tables located throughout the document that also provide the actual name for the file and its location in the directory structure. For example, a GIS shapefile that contains a map of river miles is referred in the text as "**river miles**." In Table 3-13, the alias or referenced name "**river miles**" is associated with the shapefile sac_val_stream_miles.shp located in GIS\Hydrology.

1.3 Accessing WEAP Software

The WEAP software has been under development by SEI for nearly 20 years. The software provides a comprehensive suite of tools for simulating water resources systems including rainfall-runoff hydrology, water resources infrastructure, agricultural, urban, and environmental demands, and the ability to apply complex operations rules and constraints to the water allocation problem. The water allocation problem is solved using linear programming (LP) defined by user-specified demand priorities, water supply preferences, and user-defined constraints (UDCs). The software is well documented and has a well-developed training tutorial provided on the WEAP21 website. Through an arrangement with DWR, the software is provided for free to all California public agencies. For comprehensive information on the software and downloads please visit www.weap21.org.

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Chapter 2 Water Evaluation and Planning System

The text of this chapter first appeared in various chapters of the California Water Plan, Update 2013 document on WEAP (Joyce et al., 2010). Minor edits have been made for consistency with the rest of this document.

This Chapter presents an overview of the WEAP modeling environment that provided the framework for developing both the Statewide Hydrologic Region model, Central Valley Planning Area model (CVPA), and SacWAM. Particular focus is given to the scenario analysis, water allocations, and hydrologic calculations.

2.1 General Description

The WEAP system is a comprehensive, fully integrated river basin analysis tool. It is a simulation model that includes a robust and flexible representation of water demands from different sectors, and the ability to program operating rules for infrastructure elements such as reservoirs, canals, and hydropower projects (Purkey and Huber-Lee, 2006; Purkey et al., 2007; Yates, Purkey et al., 2005; Yates, Sieber et al., 2005; Yates et al., 2008; and Yates et al., 2009). Additionally, it has watershed rainfall-runoff modeling capabilities that allow all portions of the water infrastructure and demand to be dynamically nested within the underlying hydrological processes. This functionality allows the modeler to analyze how specific configurations of infrastructure, operating rules, and operational priorities will affect water uses as diverse as instream flows, irrigated agriculture, and municipal water supply under the umbrella of input weather data and physical watershed conditions.

The WEAP software is organized into five “views”:

- Schematic View, in which the spatial layout of the model domain is created, edited and viewed.
- Data View, consisting of a hierarchical tree that organizes modeling data into six major categories: Key Assumptions, Demand Sites and Catchments, Hydrology, Supply and Resources, Water Quality, Other Assumptions and User Defined LP Constraints.
- Results View, which allows detailed and flexible display of all model outputs in customizable charts and tables. Multiple modeling scenarios can be concurrently displayed. It includes a “Favorites” option that saves useful charts, including chart formatting.
- Scenario Explorer View, in which results or data across many scenarios can be grouped together to help show the relative impacts of multiple scenarios.
- Notes View, a word processing tool for making notes or documenting aspects of the modeling analysis.

Information on navigating and using the WEAP “views” can be found in the following documents. For other questions related to the WEAP software, please see the online resources available for download at www.weap21.org.

- WEAP Water Evaluation and Planning System User Guide for WEAP 2015, August 2015

- WEAP Water Evaluation and Planning System Tutorial, January 2015.

2.2 WEAP Approach

The development of all WEAP applications follows a standard approach, as illustrated in Figure 2-1. The first step in this approach is the study definition, wherein the spatial extent and system components of the area of interest are defined and the time horizon of the analysis is set. The user subsequently defines system components (e.g., rivers, agricultural and urban demands) and the network configuration connecting these components. Following the study definition, the “current accounts” are defined, which is a baseline representation of the system – including existing operating rules to manage both supplies and demands. The current accounts serve as the point of departure for developing scenarios, which characterize alternative sets of future assumptions pertaining to policies, costs, demand factors, pollution loads, and supplies. Finally, the scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables. In this context, scenarios represent evaluations of water management response packages under uncertain future conditions. The steps in the analytical sequence are described in greater detail in the following sections.

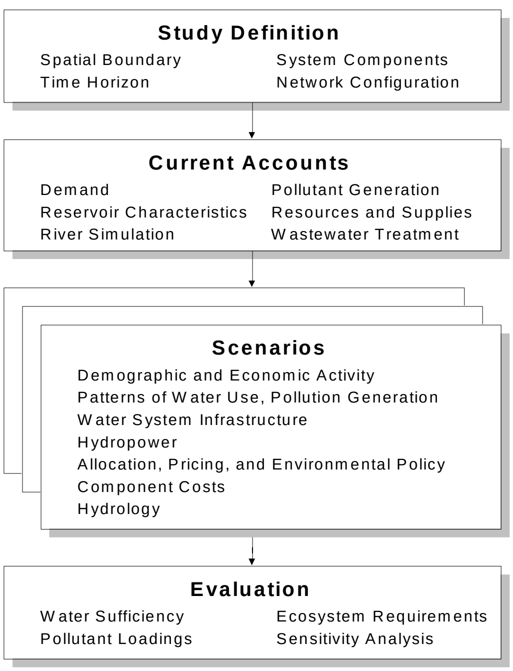

Figure 2-1. Components of a WEAP Application

2.3 Study Definition

Evaluating the implications of diversions and impoundments along a river, and how they are managed, requires consideration of the entire land area that contributes flow to the river, i.e., the river basin. Within WEAP, it is necessary to set the spatial scope of the analysis by defining the boundaries of the river basin. Within these boundaries, there are smaller rivers and streams (or tributaries) that flow into the main river of interest. Because these tributaries determine the distribution of water throughout the whole basin, it is also necessary to divide the study area into subbasins, or catchments, such that the spatial variability of stream flows can be characterized.

2.3.1 Current Accounts

Current accounts represent the basic definition of the water system as it currently exists. Current accounts include specification of supply and demand infrastructure (e.g., reservoirs, pipelines, treatment plants). *The creation and parameterization of these elements in SacWAM is described in Chapter 3 through Chapter 6*. Establishing current accounts also requires the user to calibrate system data and assumptions so as to accurately mimic the observed operation of the system. This calibration process also includes setting parameters for defined catchments so that WEAP can simulate snowmelt and rainfall-runoff using input climate data (i.e., temperature and precipitation) and also estimate evaporative water demand in the delineated basins. For details on calibration in SacWAM, see Appendices A and B.

2.3.2 Scenarios

At the heart of WEAP is the concept of scenario analysis. Scenarios are story-lines of how a future system might evolve over time. The scenarios can address a broad range of "what if" questions. In this manner, the implications of changes to the system can be evaluated, and subsequently how these changes may be mitigated by policy and/or technical interventions. For example, WEAP may be used to evaluate the water supply and demand changes for a range of future changes in demography, land use, and climate. In the case of SacWAM, the model will be used to study various in stream flow requirement scenarios and their impacts on water storage, water availability, and stream flows.

2.3.3 Evaluation

Once the performance of a set of response packages has been simulated within the context of future scenarios, the response packages can be compared relative to key metrics. Typically, these metrics relate to water supply reliability, water allocation equity, ecosystem sustainability and cost. However, any number of performance metrics can be defined and quantified within WEAP.

2.4 WEAP Water Allocation

Two user-defined priority systems are used to determine allocations of supplies to meet demands (modeled as demand sites and as catchment objects for irrigation), instream flow requirements, and for filling reservoirs. These are: (1) demand priorities, and (2) supply preferences.

A demand priority is attached to a demand site, catchment, reservoir, or flow requirement, and may range from 1 to 99, with 1 being the highest priority and 99 the lowest. Demand sites can share the same priority, which is useful in representing a system of water rights, where water users are defined by their water usage and/or seniority. In cases of water shortage, higher priority users are satisfied as fully as possible before lower priority users are considered. If priorities are the same, shortage will be shared equally (as a percentage of their demands).

When demand sites or catchments are connected to more than one supply source, the order of withdrawal is determined by supply preferences. Similar to demand priorities, supply preferences are assigned a value between 1 and 99, with lower numbers indicating preferred water sources. The assignment of these preferences usually reflects economic, environmental, historical, legal, and/or political realities. In general, multiple water sources are available when a preferred water source is insufficient to satisfy all of an area's water demands. WEAP treats additional sources as supplemental supplies and will draw from these sources only after it encounters a capacity constraint (expressed as either a maximum flow volume or a maximum percent of demand) associated with a preferred water source.

WEAP's allocation routine uses demand priorities and supply preferences to balance water supplies and demands. To do this, WEAP must assess the available water supplies each time step. While total supplies may be sufficient to meet all of the demands within the system, it is often the case that operational considerations prevent the release of water to do so. These rules are usually intended to preserve water in times of shortage so that long-term delivery reliability is maximized for the highest priority water users (often indoor urban demands). WEAP can represent this controlled release of stored water using its built-in reservoir routines.

WEAP uses generic reservoir objects, which divide storage into four zones, or pools, as illustrated in Figure 2-2. These include, from top to bottom, the flood-control zone, conservation zone, buffer zone, and inactive zone. The conservation and buffer pools together constitute a reservoir's active storage. WEAP always evacuates the flood-control zone, so that the volume of water in a reservoir cannot exceed the top of the conservation pool. The size of each of these pools can change throughout the year according to regulatory guidelines, such as flood control rule curves.

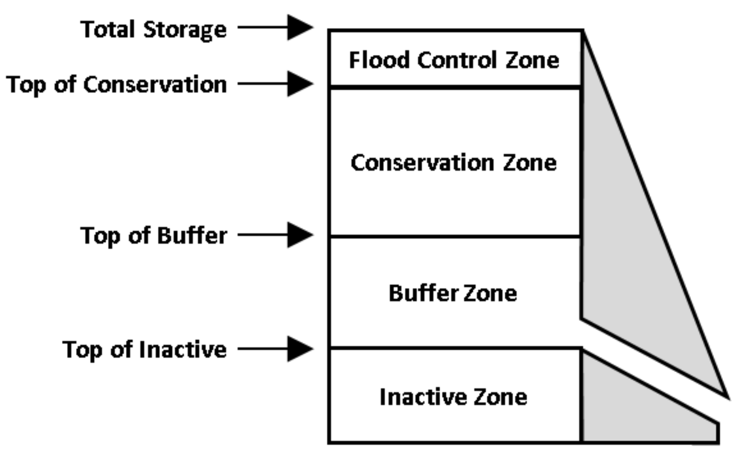

Figure 2-2. WEAP Reservoir Zones

WEAP allows reservoirs to freely release water from the conservation pool to fully meet withdrawal and other downstream requirements. Once the reservoir storage level drops into the buffer pool, the release is restricted according to the buffer coefficient, to conserve the reservoir's dwindling supplies. The buffer coefficient is the fraction of the water in the buffer zone available each month for release. Thus, a coefficient close to 1.0 will cause demands to be met more fully, while rapidly emptying the buffer zone. A coefficient close to zero will leave demands unmet while preserving the storage in the buffer zone. Water in the inactive pool is not available for allocation, although under extreme conditions evaporation may draw the reservoir below the top of the inactive pool.

2.5 WEAP Hydrology

The hydrology module in WEAP is spatially continuous, with a study area configured as a contiguous set of catchments that cover the entire extent of the represented river basin. This continuous representation of the river basin is overlaid with a water management network topology of rivers, canals, reservoirs, demand centers, aquifers, and other features (Yates, Purkey et al., 2005; Yates, Sieber et al., 2005). Each catchment is fractionally subdivided into a unique set of independent land-use or land-cover classes that lack detail regarding their exact location within the catchment, but which sum to 100 percent of the catchment's area. A unique climate data set of precipitation, temperature, relative humidity, and wind speed is uniformly prescribed across each catchment. *For details on how catchments were developed in SacWAM see Chapter 4 and Chapter 5*.

In the SacWAM application, hydrological processes are represented using two different approaches. In the mountainous upper watersheds the *Soil Moisture* method is used to represent rainfall runoff processes. This method was used in the upper watersheds due to its ability to simulate snow accumulation and melt processes and its relatively small set of input parameters. On the Sacramento Valley floor the *MABIA* method is used to represent agricultural crops and irrigation management. This method was designed for the simulation of irrigated agriculture and allows the model user to specify several irrigation related parameters.

The Soil Moisture method is one-dimensional, quasi-physical water balance model that depicts the hydrologic response of each fractional area within a catchment and partitions water into surface runoff, infiltration, evapotranspiration (ET), interflow, percolation, and baseflow components. Values from each fractional area (fa) within the catchment are then summed to represent the lumped hydrologic response for all land cover classes, with surface runoff, interflow, and baseflow being linked to a river element; deep percolation being linked to a groundwater element where prescribed; and ET being lost from the system.

The hydrologic response of each catchment is depicted by a "two-bucket" water balance model as shown in Figure 2-3. The model tracks soil water storage, in the upper bucket, z_{fa}, and in the lower bucket, Z. Effective precipitation, Pe, and applied water, AW, are partitioned into evapotranspiration (ET), surface runoff/return flow, interflow, percolation and baseflow. Effective precipitation is the combination of direct precipitation (P_{obs}) and snowmelt (which is controlled by the temperatures at which snow freezes, T_s, and melts, T_l). Soil water storage in the shallow soil profile (or upper bucket) is tracked within each fractional area, fa, and is influenced by the following parameters: a plant/crop coefficient (kc_{fa}); a conceptual runoff resistance factor (RRF_{fa}); water holding capacity (WC_{fa}); hydraulic conductivity (HC_{fa}); upper and lower soil water irrigation thresholds (U_{fa} and L_{fa}); and a partitioning fraction, f, which determines whether water moves horizontally or vertically. Percolation from each of these fractional areas contributes to soil water storage (Z) in the deep soil zone (or lower bucket) and is influenced by the following parameters: water holding capacity (WC_{fa}), hydraulic conductivity (HC_{fa}), and the partitioning fraction, f.

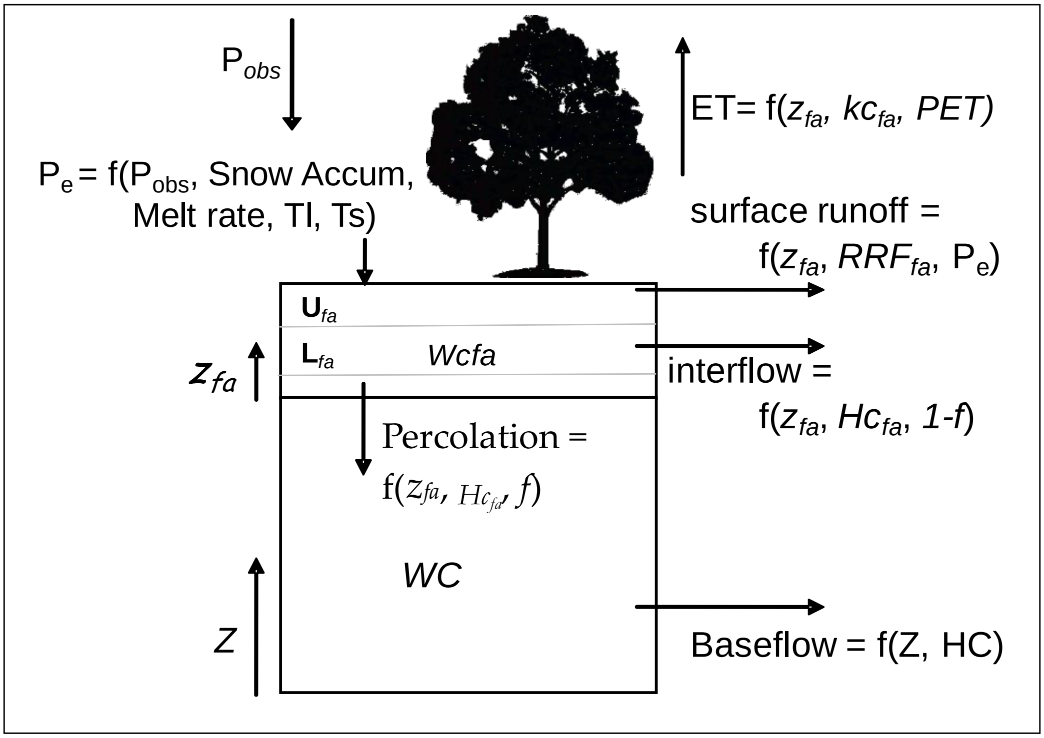

Figure 2-3. Two-Bucket Soil Moisture Method Model

The MABIA method is a daily simulation of transpiration, evaporation, irrigation requirements and scheduling, crop growth and yields, and includes modules for estimating reference evapotranspiration and soil water capacity. It was derived from the MABIA suite of software tools, developed at the Institut National Agronomique de Tunisie by Dr. Ali Sahli and Mohamed Jabloun. For more information about MABIA and to download standalone versions of the software, visit http://mabia-agrosoftware.co. The algorithms and descriptions contained here are for the combined MABIA-WEAP calculation procedure.

The MABIA Method is a one-dimensional water balance model that depicts the hydrological response within each fractional area within a catchment and partitions rainfall (P) into surface runoff (SR), infiltration (I), evapotranspiration (E and T), and deep percolation (DP) (Figure 2-4). For the calculation of evapotranspiration it uses the 'dual' Kc method, as described in FAO Irrigation and Drainage Paper No. 56 (Allen et al., 1998), whereby the Kc value is divided into a 'basal' crop coefficient, Kcb, and a separate component, Ke, representing evaporation from a shallow soil surface layer. The basal crop coefficient represents actual ET conditions when the soil surface is dry but sufficient root zone moisture is present to support full transpiration. This method also provides parameters for the user to specify irrigation efficiency and effective rainfall. This method can be used to model both agricultural crops as wells as non-agricultural land classes, such as forests and grasslands.

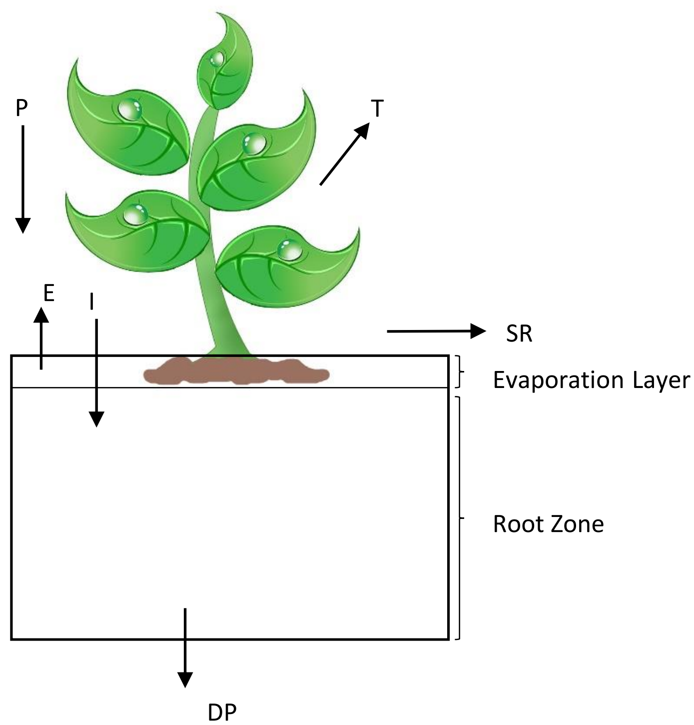

Figure 2-4. MABIA Soil Moisture Model

Although the timestep for MABIA is daily, the timestep for the rest of the WEAP analysis does not need to be daily (although it can be daily). For each WEAP timestep (e.g., monthly), MABIA would run for every day in that timestep and aggregate its results (evaporation, transpiration, irrigation requirements, runoff, and infiltration) to that timestep. For example, in January, MABIA would run from January 1 to 31, and sum up its results as January totals, including the supply requirement for irrigation. WEAP would then solve its supply allocations, using this monthly irrigation requirement from the MABIA catchments. In the case where the supply delivered to the catchments was less than the requirement, MABIA would rerun its daily simulation, this time using only the reduced amount of irrigation to determine actual evaporation, transpiration, irrigation requirements, runoff, and infiltration.

The steps in the MABIA calculations are as follows:

1. Reference Evapotranspiration (ETref)
2. Soil Water Capacity
3. Basal Crop Coefficient (K_{cb})
4. Evaporation Coefficient (K_e)
5. Potential and Actual Crop Evapotranspiration (ET_c)
6. Water Balance of the Root Zone
7. Irrigation
8. Yield

2.6 WEAP Solution Methodology

At each time step, WEAP first computes the horizontal and vertical fluxes using the catchment objects, which it passes to each river and groundwater object. Next, water allocations are made for the given time step by passing constraints related to the characteristics of reservoirs and the distribution network, environmental regulations, and the priorities and preferences assigned to demand sites to a linear programming optimization routine that maximizes demand "satisfaction" to the greatest extent possible (Yates, Sieber et al., 2005). All flows are assumed to occur instantaneously; thus, demand sites can withdraw water from the river, use some of the water consumptively, and optionally return the remainder to a receiving water body in the same time step. As constrained by the network topology, the model can also allocate water to meet any specific demand in the system, without regard to travel time. Thus, the model time step should be at least as long as the residence time of water within the study area.

A form of linear programming known as mixed integer programming (MIP) is used to solve the water allocation problem whose objective is to maximize satisfaction of demand, subject to supply priorities, demand site preferences, mass balances, and other constraints. The constraint set is iteratively defined at each time step to sequentially consider the ranking of the demand priorities and supply preferences. The approach has some attributes of a more traditional dynamic programming algorithm, where the model is solved in sequence based on the knowledge of values derived from the previous variables and equations. Individual demand sites, reservoirs, and in-stream flow requirements are assigned a unique priority number, which are integers that range from 1 (highest priority) to 99 (lowest priority). Those entities with a Priority 1 ranking are members of Equity Group 1, those with a Priority 2 ranking are members of Equity Group 2, and so on. The MIP constraint set is written to supply an equal percentage of water to the members of each Equity Group. This is done by adding to the MIP for each demand site:

- a percent coverage variable, which is the percent of the total demand satisfied at the given time step.
- an equity constraint that equally satisfies all demands within each Equity Group in terms of percentage of satisfied demand.
- a coverage constraint which ensure the appropriate amountof water supplied to a demand site or the meeting of an instream flow requirement.

The MIP is solved at least once for each Equity Group that maximizes coverage to demand sites within that Equity Group. When solving for Priority 1, WEAP will suspend (in the MIP) allocations to demands with Priority 2 and lower. Then, after Priority 1 allocations have been made that ensure equity among all Priority 1 members, Priority 2 demands are activated (but 3 and lower are still not set). Similar to demand priorities, supply preferences apply an integer ranking scheme to define which sources will supply a single demand site. Often, irrigation districts and municipalities will rely on multiple sources to meet their demands, so there is a need for a mechanism in the allocation scheme to handle these choices. To achieve this effect in the allocation algorithm, each supply to the same demand site is assigned a preference rank, and within the given priority, the MIP algorithm iterates across each supply preference to maximize coverage at each demand site. In addition, the user can constrain the flow through any transmission link to a maximum volume or a percent of demand, to reflect physical (e.g., pipe or pump capacities) or contractual limits, or preferences on mixing of supplies. These constraints, if they exist, are added to the MIP.

Upon solution of the MIP, the shadow prices on the equity constraints are examined and if non-zero for a demand site, then the water supplied for this demand site is optimal for the current constraint set. The supply set from the optimal solution of the current MIP, its equity constraint removed, and the LP is solved again for the current Equity Group and the equity constraints re-examined. This is repeated until the equity constraint for each demand site returns a positive shadow price, and their supplies set.

The MIP then iterates across the supply preferences, and this too is repeated until all the demand sites have an assigned water supply for the given Equity Group. The algorithm then proceeds to the next Equity Group. Once all Equity Groups are solved at the current time step, the algorithm proceeds to the next time step where time dependent demands and constraints are updated, and the procedure repeats.

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Chapter 3 Schematic

This chapter provides an overview of the SacWAM schematic and describes its construction using WEAP's water resources objects. The resulting schematic provides a physically-based, high-resolution representation of water supplies in the mountain and foothill watersheds, and water demands and water use on the valley floor and Delta.

3.1 Overview

The development of all WEAP applications follows a standard approach. The first step in this approach is the Study Definition, wherein the spatial extent and system components of the area of interest are defined and the time horizon of the analysis is set. The user subsequently defines System Components (e.g., rivers, agricultural and urban demands) and the network configuration connecting these components. Following the study definition, the "Current Accounts" are defined, which represents the system under existing conditions – including operating rules to manage both water supplies and water demands. The Current Accounts serve as the point of departure for developing scenarios, which characterize alternative sets of assumptions pertaining to policies, regulatory requirements, and water infrastructure. The properties of the schematic elements, as defined in the Current Accounts, are discussed in detail in Chapter 4, Chapter 5, and Chapter 6

3.1.1 Study Definition

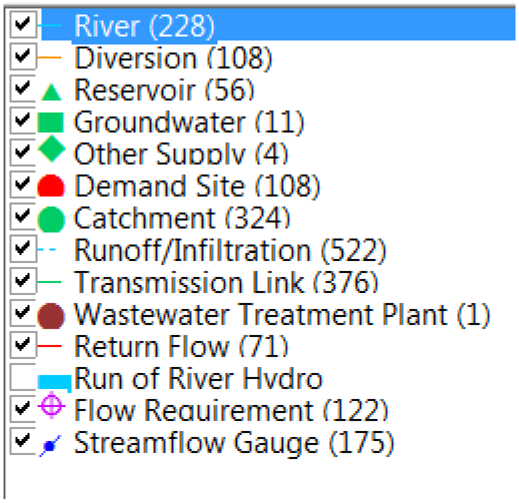
The SacWAM domain, described in Section 1.1 and presented in Figure 1-1, includes the Sacramento River Hydrologic Region and northern part of the San Joaquin River Hydrologic Region. Within this domain, SacWAM considers two types of watersheds. The first type, known as "upper" watersheds, includes the foothill and mountain watersheds of the Trinity/Cascade, Sierra Nevada, and Coast Range. These watersheds are characterized by complex topography, steep slopes, shallow soils, and limited aquifer systems. Upper watersheds are relatively undeveloped and are primarily a mix of forest, pasture, and small scattered communities. The second type of watershed, known as "valley floor" watersheds, covers the floor of the Central Valley. These watersheds are located between the upper watersheds and the Delta. In contrast to the upper watersheds, the valley floor watersheds have been extensively developed over time, are highly managed, and are composed of rich agricultural lands, refuges, and major towns and cities. Valley watersheds overlay the deep alluvial Sacramento Groundwater Basin and parts of the San Joaquin Groundwater Basin.

No single source of data has been used to construct the divide between upper and valley floor watersheds. Elevation is an imprecise indicator because of valley grades and the presence of terraces and side valleys. In general, the borders of the valley floor are defined where alluvial soils merge with bedrock features. SacWAM defines the boundary of the valley watersheds according to stream gauge locations and foothill dams, where historical streamflows are known. This flow-based boundary is typically located slightly upslope from the Sacramento and San Joaquin groundwater basin boundaries.

Shapefiles used in the construction of the model are stored within the model, and can be displayed in the model's schematic view to orient the user. File location information for these shapefiles and other files mentioned in this section is presented in Table 3-13. The GIS shape files provide visual cues in understanding and interpreting the SacWAM schematic. An example of these shape files is presented in Figure 3-1.

3.1.2 System Components

The SacWAM schematic is built using WEAP's system components that define the water supply system and the water demands. The WEAP palette of components is shown below. The following sections describe each component as it is used in SacWAM.



3.1 Rivers and Diversions

Schematic construction began with defining river, canals, and other waterways. Shapefiles were used to identify and trace hydrologic features that were added to the schematic. Shapefiles of **river miles** (RMs) and **canal miles** (CMs), developed using aerial imagery, were subsequently used to identify points of diversion, as well as other water control infrastructure.

3.1.1 River Arcs

River arcs represent rivers, streams, and other natural channels. They are represented by blue arcs in the SacWAM schematic and are listed in Table 3-1. SacWAM represents the Trinity River upstream from Lewiston, the entire Sacramento River, Feather River, and American River, and the San Joaquin River downstream from Vernalis. Additionally, the model represents streams identified by the State Water Board that will form part of Phase IV of the Bay-Delta Plan update.

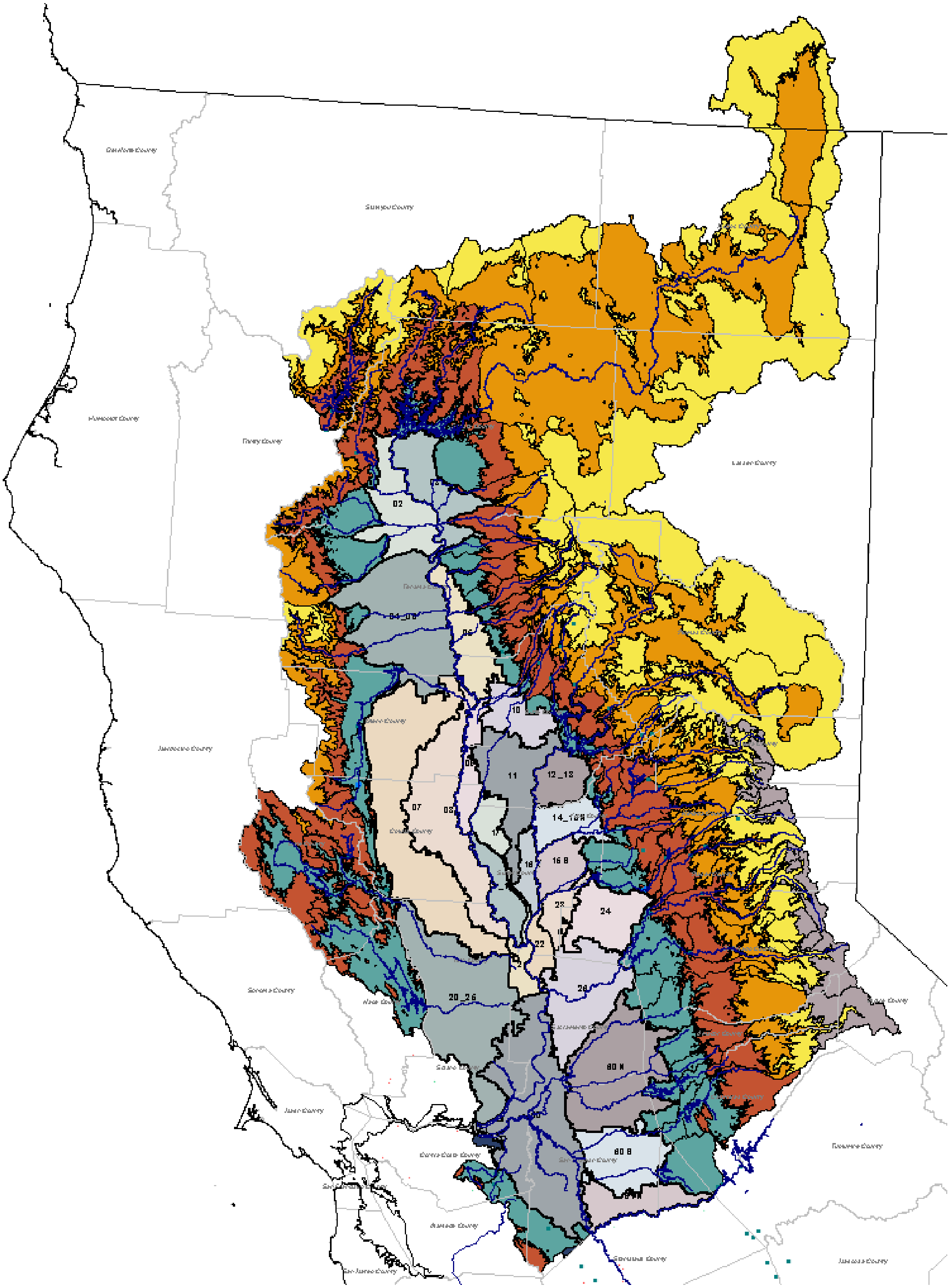


Figure 3-1. SacWAM GIS Layers

Table 3-1. Natural Waterways Represented in SacWAM

Name	Name
Antelope Creek	McCloud River
Auburn Ravine	McClure Creek
Battle Creek	Middle Fork American River
Bear River	Middle Fork Cosumnes River
Big Chico Creek	Middle Fork Feather River
Butte Creek	Middle Fork Mokelumne
Butte Slough	Middle Yuba River
Cache Creek	Mill Creek
Cache Slough	Mokelumne River
Calaveras River	North Fork American River
Camp Creek	North Fork Calaveras River
Canyon Creek	North Fork Cosumnes River
Caples Creek	North Fork Feather River
Clear Creek	North Fork Mokelumne
Cosumnes River	North Yuba River
Cottonwood Creek	Old and Middle River
Cow Creek	Oregon Creek
Deer Creek (Sacramento River tributary)	Paynes Creek
Deer Creek (Yuba River tributary)	Pit River
Dry and Hutchinson Creek	Putah Creek
Dry Creek	Rock Slough
Dry Creek (Mokelumne River tributary)	Rubicon River
Dry Creek (Yuba River tributary)	Sacramento River below Shasta
Duncan Creek	San Joaquin River below Vernalis
Echo Creek	Secret Ravine
Elder Creek	Silver Creek
Fall River	Slate Creek
Feather River below Oroville	Sly Creek
Fordyce Creek	Sly Park Creek
Georgiana Slough	South Fork American River
Gerle Creek	South Fork Calaveras River
Honcut Creek	South Fork Cosumnes River
Indian Slough	South Fork Cottonwood Creek
Jackson Creek	South Fork Feather River
Kellogg Creek	South Fork Mokelumne
Little Dry Creek	South Fork Silver Creek
Little Stony Creek	South Yuba River
Littlejohns Creek	Stony Creek
Lost Creek	Thomes Creek
Lower American River below Folsom Dam	Trinity River above Lewiston
Lower Yuba River below Englebright Dam	West Branch Feather River
Marsh Creek	Wolf Creek

WEAP places restrictions on river arcs that in certain instances prevents the arcs from being used to represent natural channels. First, flow in a river arc must be unidirectional, from upstream to downstream. Second, river arcs may flow into other river arcs as tributaries, but may not divide into two or more river arcs as distributaries. Therefore, the following diversion arcs are used to represent natural flows in SacWAM.

- **Head of Old River** diversion arc: Represents flow from the San Joaquin River to Old River.

- **Indian Slough** diversion arc: A Delta channel that links the San Joaquin River and Old River. It is important in representing regulatory flow requirements for the Old and Middle rivers. Flows through the slough bypass the Old River flow compliance location, thus south Delta water diversions have a less than 1-to-1 effect on gauged Old and Middle River reverse flows.

- **Georgiana Slough** diversion arc: A Delta channel linking the Sacramento and Mokelumne rivers. The Delta Cross Channel is also represented by a diversion arc, but is regarded as a man-made channel.

- **Qwest** diversion arc: Defined as the net westward flow of the San Joaquin River at Jersey Point averaged over a tidal cycle. In SacWAM, it represents reverse flows, which may occur when Delta diversions and agricultural demands in the south and central Delta exceed the inflow into the central Delta. It is further decribed in Section 8.7.2

- **OMR Reverse Flow** diversion arc: Represents flows from north to south in the Old and Middle rivers. Reverse flows may occur when CVP/SWP export pumping exceed flows at the Head of the Old River.

The Old and Middle rivers (OMR) between the intake to Jones Pumping Plant and the confluence with the San Joaquin River are represented by two parallel river arcs. Flow is north to south in one arc (reverse flow) and south to north in the other arc (positive flow).

Similarly, the San Joaquin River downstream from the mouth of the Mokelumne River are represented by two parallel river arcs. Flow is west to east in one arc (reverse flow) and east to west in the other arc (positive flow).

3.1.2 Diversion Arcs

Diversion arcs typically represent man-made conveyance facilities, including canals, pipelines, and hydropower penstocks. They are represented by orange arcs in the SacWAM schematic and are listed in Table 3-2.

Table 3-2. Man-Made Conveyance Facilities Represented in SacWAM

Facility	Facility	Facility
Auburn Tunnel	EBMUD Intertie	Old River and Victoria Canal Intake
BDCP Tunnels	El Dorado Canal	Palermo Canal
Bear River Canal	El Dorado Powerhouse	Pardee to Amador Link
Bella Vista Pipeline	Folsom South Canal	Power Canal
Bowman Spaulding Conduit	Freeport Intertie	Putah South Canal
Buck Loon Tunnel	Fremont Weir	Ragsdale Random
Butte Slough	French Meadows Hell Hole Tunnel	Richvale Canal
Butte Slough Outfall Gates	Glenn-Colusa Canal	Robbs Peak Tunnel
San Luis Canal	Hell Hole Tunnel	Rock Slough Intake
California Aqueduct	Joint Board Canal	Sacramento Weir
CA East and West Branches	Jones Fork Tunnel	Slate Creek Tunnel
Camino Conduit	Kelly Ridge Powerhouse	South Bay Aqueduct
Camp Creek Diversion Tunnel	Knights Landing Ridge Cut	South Canal
Camptonville Tunnel	Lohman Ridge Tunnel	South Fork Tunnel
Clear Creek Tunnel	Los Vaqueros Pipeline	South Yuba Canal
Colusa Basin Drain	Lower Boardman Canal	Spring Creek Conduit
Colusa Weir	M and T 3Bs Goose Lake	Sutter Bypass
Constant Head Orifice	Milton Bowman Tunnel	TCC to GCC Intertie
Contra Costa Canal	Miners Ranch Canal	Tehama-Colusa Canal
Cox Spill	Mokelumne Aqueduct	Tisdale Weir
Delta Cross Channel	Mokelumne Los Vaqueros Intertie	Toadtown Canal
Delta-Mendota Canal	Moulton Weir	Transfer to Contra Costa Canal
DMC-CA Intertie	Natomas Cross Canal	Western Canal
Drum Canal	Natomas East Main Drain	Wise Canal
Duncan Creek Tunnel	North Bay Aqueduct	Yolo Bypass

Additional to diversions listed in Table 3-2, the SacWAM schematic includes diversion arcs to represent other aspects of the Sacramento Valley and Delta water system. These diversion arcs include:

- **Canal Losses**: represent seepage from canals to groundwater or loss by evaporation. Canal loss arcs include those for Putah South Canal, South Yuba Canal, and Tehama-Colusa Canal.
- **Water Treatment Plant Intakes**: these diversion arcs are described in Section 3.9
- **Bias Corrections**: Outflows from the river system to correct for bias in the SacWAM hydrology. These include: Bend Bridge Outflow, Butte City Outflow, and Freeport Outflow
- **Delta Depletions**: SacWAM includes the option of using preprocessed timeseries data to represent net channel depletion within the Delta. As part of this option, the model includes seven accretion arcs (represented using river objects) and seven depletion arcs (represented using diversion objects).

The California Aqueduct, the Delta-Mendota Canal, and associated contractor water demands play a key role in SacWAM, determining the volume of exports from the south Delta. To simplify simulation of CVP and SWP joint-use facilities south of the Delta, the CVP and SWP conveyance infrastructure has been separated. The capacity of the California Aqueduct–Delta-Mendota Canal Intertie is set to zero and the capacity of the Delta-Mendota Canal is modeled as 4,600 cfs along its entire reach.[3]

3.1.2.1 *California Aqueduct*

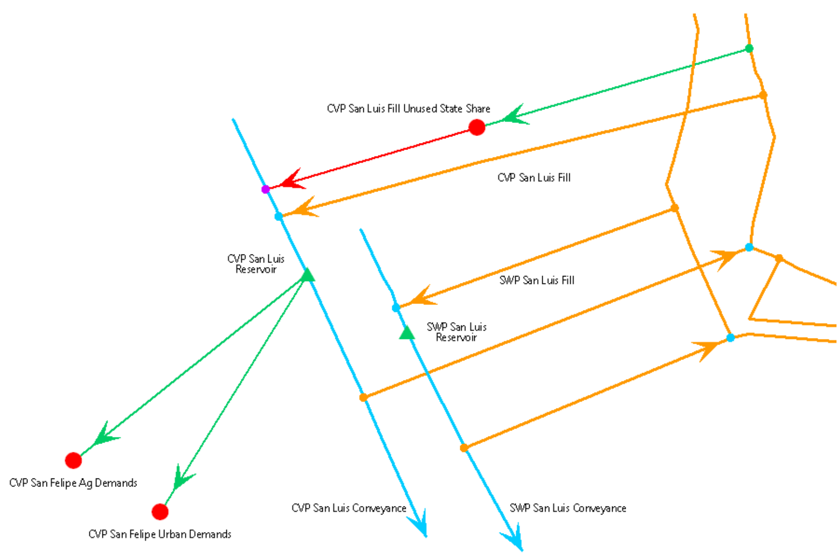
SacWAM represents the California Aqeduct, stretching from Clifton Court Forebay to the division in to the West and East Branches. The SWP share of the joint-reach (known as the San Luis Canal) is treated as an integral part of the aqueduct. The CVP share of the joint-reach is modeled as a separate canal diverting from the Delta-Mendota Canal downstream from O'Neill Pumping Plant and San Luis Reservoir.

3.1.2.1 *Delta-Mendota Canal*

SacWAM represents the 117-mile long Delta-Mendota Canal from the Jones Pumping Plant to the Mendota Pool. To represent diversions from the Mendota Pool, the SacWAM schematic includes the reach of the San Joaquin River from Mendota Dam to Sack Dam and inflows from the James Bypass and the San Joaquin River below the Chowchilla Bifurcation Structure.

3.1.2.2 *O'Neill and Gianelli Pumping Generating Plants*

The CVP and SWP share of San Luis Reservoir are represented as distinct reservoirs. WEAP contains no objects for offstream reservoirs; reservoir objects must be located on a river arc. Therefore, SacWAM uses two artificial river to locate the CVP and SWP shares of San Luis Reservoir.



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[3] The purpose of the Intertie is to improve Delta-Mendota Canal conveyance limitations that restrict the Jones Pumping Plant to less than its design capacity of 4,600 cfs and to improve operational flexibility for operations, maintenance, and emergency activities. The Delta-Mendota Canal capacity upstream from the O'Neill Forebay and the pumping capacity at O'Neill Pumping Plant is about 4,200 cfs Therefore, before the Intertie was built, pumping at Jones Pumping Plant could only exceed 4,200 cfs if deliveries were made to contractors located upstream from the O'Neill Pumping Plant.

The O`Neill Pump-Generating Plant consists of an intake channel leading off the Delta-Mendota Canal and six pump-generating units. Normally these units operate to lift water into the O`Neill Forebay. From there CVP water flows through the joint-reach or is lifted into San Luis Reservoir by the Gianelli Pump-Generating Plant. Water released from the reservoir generates power as it passes back through the Gianelli Pump-Generating Plant. CVP water may subsequently flow back to the Delta-Mendota Canal through the O`Neill Pump-Generating Plant.

Simulation of the CVP and SWP shares of San Luis Reservoir requires multiple arcs linking the California Aqueduct and Delta-Mendota Canal to the two simulated reservoir. One set of arcs represents flow of CVP water from the O'Neill Pumping Plant and the Gianelli Pumping Plant to fill the reservoir and the release of CVP water back to the Joint-Reach or Delta-Mendota Canal. A similar pair of arcs represents the flow of SWP water through the Gianelli Pump-Generating Plant either to fill or drain the reservoir.

3.2 Reservoirs

SacWAM represents all major water supply reservoirs within the model domain having a storage capacity in excess of 50,000 acre-feet. SacWAM also represents reservoirs used for hydropower, in cases where there storage regulation significantly affects seasonal river flows downstream. Additionally, smaller reservoirs are included in the schematic to help orientate the model user or to define points of diversion, for example, Lewiston Reservoir on the Trinity River provides a forebay for diversions to the Sacramento Valley through the Clear Creek Tunnel. Table 3-3 lists the reservoirs contained in SacWAM, the owner/operator, and storage capacity.

Table 3-3. Reservoirs Represented in SacWAM

Reservoir	SacWAM River	Owner/Operator	Capacity (TAF)
Black Butte Reservoir	Stony Creek	Reclamation/CVP	144
Bowman Lake	Canyon Creek	Nevada Irrigation District	64
Bucks Lake	North Fork Feather River	PG&E	103
Butt Valley	North Fork Feather River	PG&E	50
Camanche Reservoir	Mokelumne River	EBMUD	417
Camino Reservoir	Silver Creek	Sacramento Municipal Utility District	<1
Camp Far West	Bear River	South Sutter WD	105
Caples Lake	Caples Creek	PG&E	22
Chili Bar Reservoir	South Fork American River	PG&E	4
Clear Lake	Cache Creek	Yolo County FC&WCD	1,155
Clifton Court Forebay	Old and Middle River	DWR/SWP	29
CVP San Luis Reservoir	Offstream	Reclamation/CVP	973
East Park Reservoir	Little Stony Creek	Reclamation/Orland WUA	51
EBMUD Terminal Reservoirs	Mokelumne Aqueduct	EBMUD	155
Englebright Reservoir	Yuba River	USACE	70
Farmington Reservoir	Littlejohns Creek	USACE	52
Folsom Lake	American River	Reclamation/CVP	977
French Meadows	Middle Fork American River	Placer County Water Agency	136
Frenchman Lake	Middle Fork Feather River	DWR/SWP	55
Hell Hole	Rubicon River	Sacramento Municipal Utility District	208
Ice House	South Fork Silver Creek	Sacramento Municipal Utility District	44
Indian Valley Reservoir	North Fork Cache Creek	Yolo County FC&WCD	300
Jackson Meadows Reservoir	Middle Fork Yuba River	Nevada Irrigation District	69
Jenkinson Lake	Sly Park Creek	El Dorado Irrigation District	41
Keswick Reservoir	Sacramento River	Reclamation/CVP	24
Lake Almanor	North Fork Feather River	PG&E	1,308
Lake Amador	Jackson Creek	Jackson Valley Irrigation District	22
Lake Berryessa	Putah Creek	Reclamation/Solano Project	1,602
Lake Combie	Bear River	Nevada Irrigation District	6
Lake Davis	Middle Fork Feather River	DWR/SWP	83
Lake Fordyce	Fordyce Creek	PG&E	48
Lake Natoma	American River	Reclamation/CVP	9
Lake Spaulding	South Fork Yuba River	PG&E	75
Lewiston Lake	Trinity River	Reclamation/CVP	15
Little Grass Valley Reservoir	South Fork Feather River	South Feather Water and Power Agency	93
Loon Lake	Gerle Creek	Sacramento Municipal Utility District	77
Los Vaqueros Reservoir	Kellogg Creek	Contra Costa Water District	160
Merle Collins Reservoir	French Dry Creek	Browns Valley Irrigation District	57
New Bullards Bar Reservoir	Yuba River	Yuba County Water Agency	970
New Hogan Reservoir	Calaveras River	Reclamation/Stockton East WD	317
Oroville Reservoir	Feather River	DWR/SWP	3,538
Pardee Reservoir	Mokelumne River	EBMUD	210
PG&E Upper Watershed Reservoirs	North Fork Mokelumne River	PG&E	194
Rollins Reservoir	Bear River	Nevada Irrigation District	66
Scotts Flat Reservoir	Deer Creek – Yuba River tributary	Nevada Irrigation District	49
Shasta Lake	Sacramento River	Reclamation/CVP	4,552
Silver Lake	Silver Fork American	PG&E	4
Slab Creek Reservoir	South Fork American River	Sacramento Municipal Utility District	17
Sly Creek Reservoir	Lost Creek	South Feather Water and Power Agency	65
Stony Gorge Reservoir	Stony Creek	Reclamation/Orland WUA	50
SWP San Luis Reservoir	Offstream	DWR/SWP	1,067
Thermalito Afterbay	Power Canal	DWR/SWP	57
Trinity Reservoir	Trinity River	Reclamation/CVP	2,448
Union Valley Reservoir	Silver Creek	Sacramento Municipal Utility District	266
Whiskeytown Reservoir	Clear Creek	Reclamation/CVP	241

Key: CVP=Central Valley Project; DWR=Department of Water Resources; SWP = State Water Project; TAF=thousand acre-feet

3.3 Groundwater

Ten groundwater basins are simulated in SacWAM using the WEAP groundwater objects. The horizontal extents of the basins are shown in Figure 3-2. The basins are aggregated from Bulletin 118 Groundwater Basins (DWR, 2014a) as shown in Table 3-4. The **Bulletin 118 GW basins** shapefile was used to create the SacWAM **groundwater basins** shapefile.

Inflows and outflows to and from the groundwater basins include: (1) deep percolation from demand unit catchment objects, (2) return flows from urban demand sites, (3) seepage losses on surface water distribution systems, (4) interaction with the stream network through the *Groundwater Inflow* and *Groundwater Outflow* parameters on stream reaches, and (5) groundwater pumping to meet catchments and demand site water demands.

In the SacWAM schematic, vertical recharge from catchment objects to the groundwater basins are shown by dashed blue runoff/infiltration arcs, return flows from demand sites are indicated by red arcs, and groundwater pumping is represented by green transmission links. Other groundwater flow components, though simulated, are not represented in the schematic.

Table 3-4. Relationship between SacWAM Groundwater Objects and Bulletin 118 Basins

SacWAM Groundwater Basin	Bulletin 118 Basins
Redding	South Battle Creek, Bowman, Rosewood, Anderson, Enterprise, Millville
Red Bluff Corning	Bend, Antelope, Dye Creek, Corning, Red Bluff, Vina, Los Molinos
Colusa	Colusa
Butte	East Butte, West Butte
Sutter Yuba	North Yuba, South Yuba, Sutter
Yolo Solano[1]	Yolo, Solano
American[1]	North American, South American
Cosumnes	Cosumnes
Eastern San Joaquin[1]	Eastern San Joaquin
Delta[1]	Not represented
Suisun[2]	Suisun-Fairfield

Notes:
[1] Parts of Yolo Solano, American, and Eastern San Joaquin are represented as part of the Delta groundwater object. The boundaries of the Delta groundwater object coincide with the Delta boundaries.
[2] Only a small portion of the Suisun-Fairfield groundwater basin is represented in SacWAM.

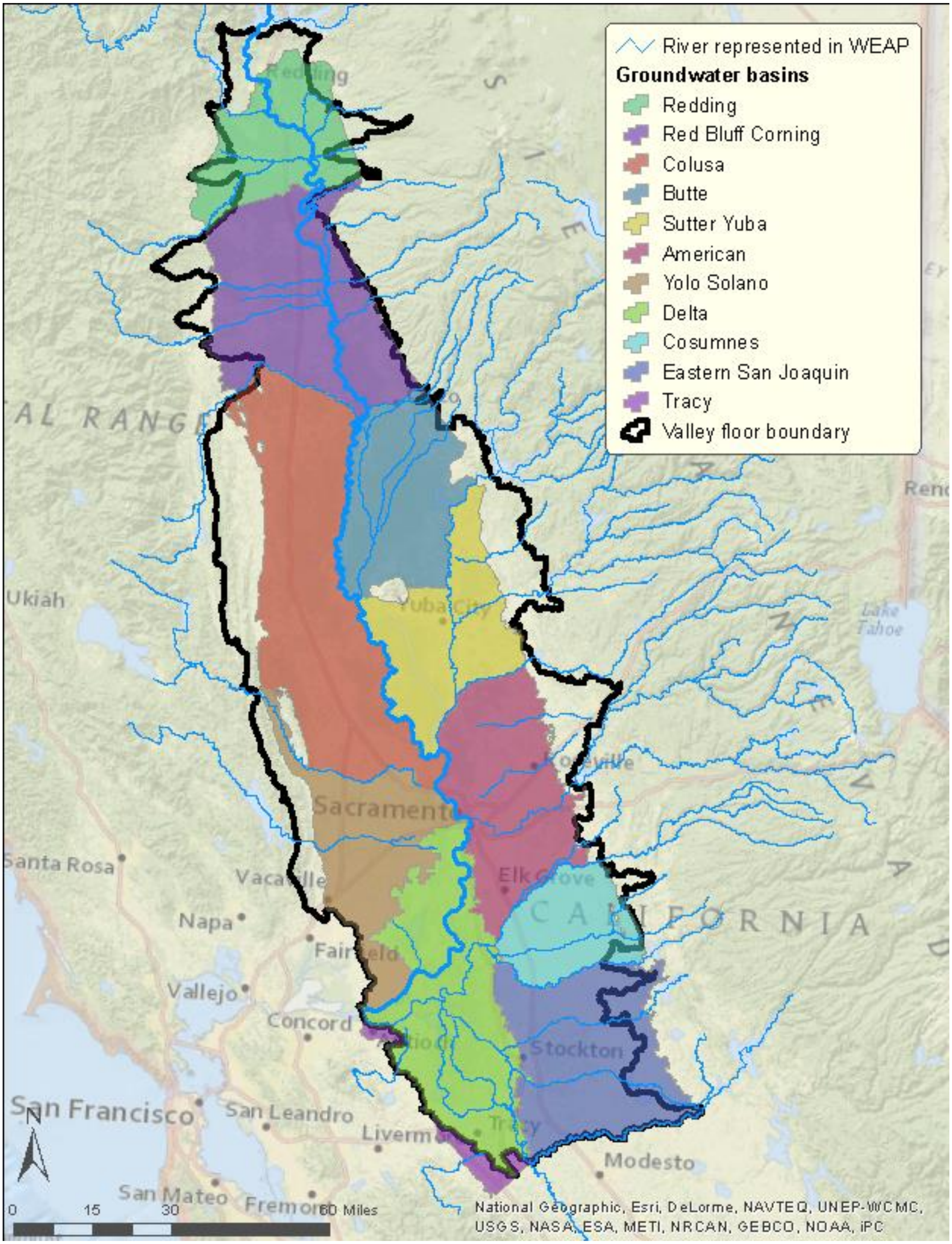


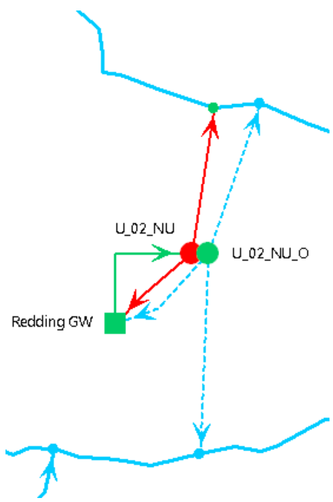
Figure 3-2. Groundwater Basins

3.4 Other Supplies

The use of the 'Other Supply' object in SacWAM is limited to the San Joaquin Valley. It provides water to lands on the southern boundary of the model domain located between the Calaveras and Stanislaus rivers, east of the San Joaquin River. The Other Supply represents: (1) water that is diverted from the Stanislaus River and flows into the Calaveras watershed; and (2) water used by riparian diverters along the San Joaquin River that extract their water upstream from Vernalis. It is assumed that these supplies are sufficient to meet the water demands of the local water users.

3.5 Demand Sites

WEAP's demand sites are used to represent urban water demands and deliveries to water users located outside the model domain (e.g., CVP and SWP south-of-Delta contractors). Rainfall-runoff and deep percolation from urban lands is represented using a WEAP catchment object associated with each urban demand site within the model domain. In the example shown, the demand site is DU U_02_NU and the associated catchment object is U_02_NU_O ("_O" denoting outdoor).



Urban demand sites are discussed in Chapter 4 and are listed in section Table 4-3.

3.6 Catchments

Catchment objects were added to the schematic to represent groups of water users on the valley floor, known as demand units (DUs). These are described in detail in Sections 4.1.1 and 4.1.2.

The spatial extents of **water budget areas** (WBAs) and **demand units** were used to determine catchment placement in the SacWAM model-building process. Because there are multiple, non-contiguous polygons associated with a single DU in SacWAM but there is only a single catchment object used to represent that DU, a DU's catchment placement in the model is only accurate within its WBA boundary.

3.7 Runoff/Infiltration

3.7.1 Surface Runoff and Return Flows

A comprehensive, GIS-based approach was used to determine surface water runoff and return flow locations for SacWAM DUs. This approach ensured the accurate simulation of flows of tributary rivers at their confluences with the Sacramento River, the accurate simulation of flows at USGS gauges on the Sacramento River, and flows into the Delta (Figure 1-2, Figure 1-3).

The contributing watersheds for each of these return points of interest (**valley floor returns**) were delineated through a combination of GIS tools and the use of the Natural Resources Conservation Service (NRCS) **Hydrologic Unit Code (HUC)-12 watersheds** dataset (NRCS, 2013a). In the case where the point of interest fell on a boundary between two NRCS **HUC-12 watersheds**, the HUC-12 boundary was used. In all other cases the watershed tool in ArcGIS was used to delineate the downstream extent of the watershed boundary using the National Hydrography Dataset (NHD) **flow accumulation** grid and the NRCS **HUC-12 watersheds** were used from the point that the GIS-generated watershed boundary intersected the HUC-12 boundary. There are two places where the approach was amended. These include the American River and Rodeo Creek, where relevant flow details are not captured in the NRCS **HUC-12 watersheds**. Rodeo Creek flows into McClure Creek, rather than directly into the Sacramento River as suggested by the HUC-12 boundaries. For this reason, the approximate area of the Rodeo Creek HUC-12 that drains to Rodeo Creek was added to the contributing area for McClure Creek. The American River watershed was divided along a boundary established in DWR models (**American boundaries**). The resulting file is called **watershed boundaries**.

Once SacWAM watershed boundaries were determined, an intersection was performed with the **demand units** and **watershed boundaries** shapefiles. The result of this intersection is the surface **returns intersection** shapefile. This intersection determined the proportion of each DU that lies within each SacWAM watershed. Where the percentage of a DU that lies within each SacWAM watershed is less than or equal to 10%, the return was not represented on the schematic and proportions were recalculated with the watersheds less than or equal to 10% omitted from the total area. The post-intersection processing is documented in the **surface returns** file. Table 3-5 presents surface runoff and return information for each DU, with the percentage of runoff/return flow that contributes to each return location. On the schematic, surface runoff and return locations are referred to with an “SR” preceding location names. For instance, surface runoff to Cottonwood Creek from DU A_02_NA is referred to as “SR Cottonwood Creek” in Table 3-5 and in SacWAM.

Surface runoff is represented in SacWAM with a runoff link to a surface water body (dashed blue line). If a catchment has multiple receiving surface water bodies, the runoff is distributed among the return locations using the surface returns intersection. The corresponding percentage of runoff that contributes to each return location (indicated in Table 3-5 and the **surface returns** file) was entered in the *Supply and Resources\Runoff and Infiltration\Demand Unit\Inflows and Outflows\Surface Runoff Fraction* branch of the data tree.

There are some urban DUs that represent both municipalities and scattered urban communities. For example, U_02_NU represents the City of Anderson, Cottonwood WD, Lake California (Rio Alto WD) and small communities (self-supplied). The municipalities hold permits to discharge wastewater to the Sacramento River at RM 281, but the small communities do not. In SacWAM, these DUs are represented with multiple return flows. One return flow link will flow to the wastewater treatment plant (WWTP) discharge location, and the other link(s) will flow to the groundwater basin(s) which the DU overlies. The rainfall runoff from this DU type will flow to surface water locations as determined by the surface **returns intersection**.

The exceptions to the approach described above were the DUs that encompass the Delta. These are: A_50_NA1, A_50_NA2, A_50_NA3, A_50_NA4, A_50_NA5, A_50_NA6, and A_50_NA7, which have runoff to specified RMs. Because the HUC-12 watersheds may be an imprecise indicator of flow in the Delta, surface returns from CalSim II were used instead (Reclamation, 2007).

Runoff to surface water bodies from urban catchments was treated in the same way as from agricultural catchments. Surface runoff locations and percentages were determined from the surface **returns intersection** for each DU. In cases where a DU only represents municipalities that hold a permit to discharge to a WWTP, it is assumed that 100% of the runoff from the urban DU's catchment flows to the WWTP discharge location. The parameter values are contained in the surface returns file.

Table 3-5. Surface Runoff from Demand Units

Demand Unit	Return Flow Node and Percent of Runoff	Demand Unit	Return Flow Node and Percent of Runoff
A_02_NA	SR Cottonwood Ck (84%)	A_11_SA3	Butte Ck (52%)
	SR Sacramento R ab Keswick Gauge (16%)		Sutter Bypass (48%)
A_02_PA	SR Sacramento R ab Bend Bridge Gauge (62%)	A_11_SA4	Sutter Bypass (100%)
	SR Cottonwood Ck (23%)	A_12_13_NA	SR Feather R (100%)
	SR Clear Ck (15%)	A_12_13_SA	SR Feather R (80%)
A_02_SA	SR Sacramento R ab Bend Bridge Gauge (54%)		SR Feather R ab Gridley Gauge (20%)
	SR Cottonwood Ck (46%)	A_14_15N_NA1	SR Feather R (100%)
A_03_NA	SR Sacramento R ab Bend Bridge Gauge (85%)	A_14_15N_NA2	SR Feather R (100%)
	SR Cow Ck (15%)	A_14_15N_NA3	SR Yuba R ab Marysville Gauge (58%)
A_03_PA	SR Sacramento R ab Bend Bridge Gauge (75%)		SR Feather R (42%)
	SR Cow Ck (25%)	A_14_15N_SA	SR Feather R (100%)
A_03_SA	SR Sacramento R ab Bend Bridge Gauge (100%)	A_15S_NA	SR Bear R (74%)
A_04_06_NA	SR Sacramento R ab Hamilton City Gauge (83%)		SR Feather R (26%)
	SR Thomes Ck (17%)	A_15S_SA	SR Feather R (100%)
A_04_06_PA1	SR Sacramento R ab Hamilton City Gauge (56%)	A_16_NA	Sutter Bypass (100%)
	SR Sacramento R ab Vina Gauge (44%)	A_16_PA	Sutter Bypass (100%)
A_04_06_PA2	SR Sacramento R ab Hamilton City Gauge (100%)	A_16_SA	Sutter Bypass (100%)
A_04_06_PA3	SR Stony Ck (28%)	A_17_NA	Sutter Bypass (100%)
	SR Sacramento R ab Ord Ferry Gauge (28%)	A_17_SA	Sutter Bypass (100%)
	SR Colusa Basin Drain (21%)	A_18_19_NA	Sutter Bypass (100%)
	SR Sacramento R ab Hamilton City Gauge (12%);	A_18_19_SA	Sutter Bypass (100%)
	SR Sacramento R ab Butte City Gauge (11%)	A_20_25_NA1	SR Yolo Bypass (53%)
A_05_NA	SR Sacramento R ab Hamilton City Gauge (100%)		SR Cache Ck (31%)
A_07_NA	SR Colusa Basin Drain (100%)		SR Cache Ck ab Yolo Gauge (16%)
A_07_PA	SR Colusa Basin Drain (100%)	A_20_25_NA2	SR Sacramento R ab Rio Vista Gauge (87%)
A_08_NA	SR Colusa Basin Drain (100%)		SR Sacramento R RM 003 (13%)
A_08_PA	SR Colusa Basin Drain (100%)	A_20_25_PA	SR Sacramento R ab Rio Vista Gauge (100%)
A_08_SA1	SR Colusa Basin Drain (100%)	A_21_NA	SR Yolo Bypass (100%)
A_08_SA2	SR Colusa Basin Drain (100%)	A_21_PA	SR Yolo Bypass (100%)
A_08_SA3	SR Colusa Basin Drain (100%)	A_21_SA	SR Yolo Bypass (100%)
A_09_NA	SR Butte Ck (87%)	A_22_NA	SR Natomas East Main Drain (100%)
	SR Sacramento R ab Butte City Gauge (13%)	A_22_SA1	SR Natomas East Main Drain (77%)
A_09_SA1	SR Butte Ck (88%)		SR Sacramento R ab Verona Gauge (23%)
	SR Sacramento R ab Ord Ferry Gauge (12%)	A_22_SA2	SR Sacramento R above Verona Gauge (100%)
A_09_SA2	SR Butte Ck (100%)	A_23_NA	Auburn Ravine RM 000 (76%)
A_10_NA	SR Butte Ck (100%)		SR Bear R (24%)
A_11_NA	Sutter Bypass (100%)	A_24_NA1	Auburn Ravine RM 000 (84%)
A_11_SA1	SR Butte Ck (100%)		SR Auburn Ravine (16%)
A_11_SA2	Butte Ck (100%)		

Table 3-5. Surface Runoff from Demand Units contd.

Demand Unit	Return Flow Node and Percent of Runoff	Demand Unit	Return Flow Node and Percent of Runoff
A_24_NA2	Auburn Ravine RM 000 (83%)	A_60N_NA1	SR Jackson Ck (87%)
	SR Bear R (17%)		SR Dry Ck (13%)
A_24_NA3	SR Auburn Ravine (29%)	A_60N_NA2	SR Cosumnes R (100%)
	SR Dry Ck (27%)	A_60N_NA3	SR San Joaquin R 57%)
	SR Secret Ravine (22%)		SR Mokelumne R (43%)
	Natomas Cross Canal (22%)	A_60N_NA4	SR Mokelumne R (73%)
A_26_NA	SR Mokelumne R (70%)		SR San Joaquin R (27%)
	SR American R above Fair Oaks Gauge (17%)	A_60N_NA5	SR Cosumnes R (56%)
	SR Natomas East Main Drain (13%)		SR Dry Ck (24%)
A_50_NA1	Sacramento R RM 041 (100%)		SR San Joaquin R (20%)
A_50_NA2	Sacramento R RM 017 (100%)	A_60S_NA	SR San Joaquin R (100%)
A_50_NA3	Sacramento R RM 000 (100%)	A_60S_PA	SR San Joaquin R (76%)
A_50_NA4	Mokelumne R RM 004 (100%)		SR Calaveras R (24%)
A_50_NA5	San Joaquin R RM 026 (100%)	A_61N_PA	SR San Joaquin R (100%)
A_50_NA6	San Joaquin R RM 013 (100%)	A_61N_NA1	SR Stanislaus R (47%)
A_50_NA7	Old R RM 027 (100%)		SR Littlejohns Ck (37%)
A_60N_NA1	SR Jackson Ck (87%)		SR San Joaquin R (16%)
	SR Dry Ck (13%)	A_61N_NA2	SR Stanislaus R (100%)
A_60N_NA2	SR Cosumnes R (100%)	A_61N_NA3	SR San Joaquin R (100%)
A_60N_NA3	SR San Joaquin R 57%)	U_02_NU	SR Cottonwood Ck (53%)
	SR Mokelumne R (43%)		SR Sacramento R above Bend Bridge Gauge (47%)
A_60N_NA4	SR Mokelumne R (73%)	U_02_PU	Sacramento R RM 287 (100%)
	SR San Joaquin R (27%)	U_02_SU	Sacramento R RM 287 (100%)
A_24_NA2	Auburn Ravine RM 000 (83%)	U_03_NU	SR Sacramento R above Vina Gauge (100%)
	SR Bear R (17%)	U_03_PU	Sacramento R RM 281 (100%)
A_24_NA3	SR Auburn Ravine (29%)	U_03_SU	Sacramento R RM 281 (100%)
	SR Dry Ck (27%)	U_04_06_NU	SR Sacramento R above Vina Gauge (87%)
	SR Secret Ravine (22%)		SR Sacramento R above Ord Ferry Gauge (13%)
	Natomas Cross Canal (22%)	U_05_NU	SR Sacramento R above Vina Gauge (69%)
A_26_NA	SR Mokelumne R (70%)		SR Antelope Ck (31%)
	SR American R above Fair Oaks Gauge (17%)	U_07_NU	SR Colusa Basin Drain (100%)
	SR Natomas East Main Drain (13%)	U_08_NU	SR Colusa Basin Drain (100%)
A_50_NA1	Sacramento R RM 041 (100%)	U_09_NU	SR Butte Ck (100%)
A_50_NA2	Sacramento R RM 017 (100%)	U_10_NU1	Sacramento R RM 195 (100%)
A_50_NA3	Sacramento R RM 000 (100%)	U_10_NU2	SR Butte Ck (100%)
A_50_NA4	Mokelumne R RM 004 (100%)	U_11_NU1	Feather R RM 063 (100%)
A_50_NA5	San Joaquin R RM 026 (100%)	U_11_NU2	Sutter Bypass (50%)
A_50_NA6	San Joaquin R RM 013 (100%)		Butte Ck (50%)
A_50_NA7	Old R RM 027 (100%)		

Table 3-5. Surface Runoff from Demand Units contd.

Demand Unit	Return Flow Node and Percent of Runoff	Demand Unit	Return Flow Node and Percent of Runoff
U_12_13_NU1	Feather R RM 063 (100%)	U_26_PU5	American R RM 007 (85%)
U_12_13_NU2	SR Feather R (100%)		Sacramento R RM 048 (15%)
U_14_15N_NU	Feather R RM 028 (100%)	U_60N_NU1	San Joaquin R RM 024 (100%)
U_15S_NU	Feather R RM 025 (100%)	U_60N_NU2	SR Cosumnes R (100%)
U_16_NU	Sutter Bypass (100%)	U_60N_PU	SR Cosumnes R (100%)
U_16_PU	Feather R RM 028 (100%)	U_60S_NU1	San Joaquin R RM 042 (100%)
U_17_NU	Sutter Bypass (100%)	U_60S_NU2	SR Calaveras R (100%)
U_18_19_NU	Sutter Bypass (100%)	U_61N_NU2	SR San Joaquin R (57%)
U_20_25_NU	Yolo Bypass CM 032 (100%)		SR Stanislaus R (43%)
U_20_25_PU	Cache Slough RM 005 (100%)	U_ANTOC	None
U_21_NU	SR Yolo Bypass (100%)	U_CCWD	None
U_21_PU	SR Yolo Bypass (100%)	U_CLLPT	None
U_22_NU	SR Natomas East Main Drain (100%)	U_EBMUD	None
U_23_NU	SR Natomas East Main Drain (100%)	U_ELDID	None
U_24_NU1	Auburn Ravine RM 027 (100%)	U_FVTB	None
U_24_NU2	Natomas Cross Canal CM 002 (50%)	U_JLIND	None
	Natomas East Main Drain CM 007 (50%)	U_NAPA	None
U_26_NU1	SR Natomas East Main Drain (79%)	U_PCWA3	None
	American R RM 007 (21%)	R_08_PR	SR Colusa Basin Drain above HWY 20 Gauge (80%)
U_26_NU2	American R RM 007 (100%)		SR Colusa Basin Drain above Outfall Gates Gauge (20%)
U_26_NU3	Sacramento R RM 048 (100%)	R_09_PR	SR Butte Creek (100%)
U_26_NU4	SR Mokelumne R (56%)	R_11_PR	SR Butte Creek (100%)
	Sacramento R RM 048 (32%); American R RM 007 (12%)	R_17_NR	Butte Creek (100%)
U_26_NU5	American R RM 007 (100%)	R_17_PR1	Butte Creek (100%)
U_26_NU6	SR American R above Fair Oaks Gauge (100%)	R_17_PR2	Sutter Bypass (100%)
U_26_PU1	Dry Creek (100%)		
U_26_PU2	SR Natomas East Main Drain (72%)		
	SR American R above Fair Oaks Gauge (15%)		
	American R RM 007 (13%)		
U_26_PU3	SR American R above Fair Oaks Gauge (73%)		
	American R RM 007 (27%)		
U_26_PU4	Sacramento R RM 048 (100%)		
U_61N_NU1	SR San Joaquin R (100%)		

Key: ab=above; Ck=creek; CM=canal mile; R=River; RM=river mile; SR=surface runoff; WWTP=wastewater treatment plant

For some urban DUs, the surface **returns intersection** was not used to determine return flows and/or surface runoff locations. Treated wastewater from large urban centers, with dedicated or regional WWTPs, may be discharged to surface waters. However, in most rural and smaller towns, wastewater typically is discharged to private systems or evaporation ponds, which recharge the underlying groundwater aquifer. An example of a DU that holds a permit to discharge to a surface water body is U_26_NU1. Wastewater from the municipalities represented by this DU is treated at the Sacramento Regional WWTP and discharged to the Sacramento River at RM 048. For municipalities that hold permits to discharge to surface water, it was assumed in SacWAM that 100% of the return flow and 100% of the surface runoff return to the specified WWTP location.

3.8 Transmission Links

Transmission links connect water supplies to water demands, represented in WEAP by "Demand Site" objects and "Catchment" objects. Points of diversion for CVP/SWP contractors were identified using a variety of sources, including CVP contract documents[4] (Reclamation, 2013a), the SWP Handbook (DWR, 1992), and the Delta-Mendota Canal Structures (Reclamation 1986). Non-Project points of diversion were identified using a combination of SWRCB's Electronic Water Rights Information Management System (eWRIMS) database (SWRCB, 2014), Bulletin 23 (DWR, 1924-1962) and Bulletin 130 (DWR, 1963-1975, 1988) data, and aerial imagery. SacWAM's surface water diversion are summarized in Table 3-6, Table 3-7, and Table 3-8.

3.8.1 Central Valley Project Diversions

Under the terms of its authorization, the CVP provides water to Sacramento River water right settlement contractors (settlement contractors) in the Sacramento Valley; San Joaquin River exchange contractors (exchange contractors) and water right holders in the San Joaquin Valley; agricultural and municipal and industrial (M&I) water service contractors in both the Sacramento and San Joaquin valleys; and wildlife refuges both north and south of the Delta.

Reclamation's long-term water service contracts for CVP diverters give exact locations of surface water diversions by RM for each contractor that diverts from the Sacramento River. SacWAM **river miles** were defined from recent aerial imagery. In contrast, CVP contract miles are based on the historical path of the river. Consequently, CVP contract miles have been adjusted to SacWAM RMs.

Diversion locations that are determined from CVP contracts (Reclamation, 2013a) are indicated in the "Contract Type" column of Table 3-6, Table 3-7 and Table 3-8. Those indicated as "Other" in this column were determined using a combination of sources, including Bulletin 23 and 130 data, the eWRIMS database, CalSim II, and aerial imagery.

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[4] Reclamation's long-term water service contracts for CVP diverters give exact locations of surface water diversions by RM for each contractor that diverts from the Sacramento River. SacWAM river miles were defined from recent aerial imagery. In contrast, CVP contract miles are based on the historical path of the river. Consequently, CVP contract miles have been adjusted to SacWAM RMs.

3.8.2 State Water Project Diversions

The SWP operates under long-term contracts with 29 public water agencies. These agencies deliver water to wholesalers or retailers, or deliver water directly to agricultural and M&I water users. Additionally, DWR has signed "settlement" agreements with senior water right holders on the Feather River to resolve water supply issues associated with the operation of SWP facilities associated with Lake Oroville and Thermalito Forebay and Afterbay.

3.8.2.1 *Feather River Service Area*

Three SWP long-term contractors are located north of the Delta: Plumas County Flood Control and Water Conservation District (FC&WCD), Butte County, and the City of Yuba City. Plumas County FC&WCD is located upstream from Lake Oroville in the upper Feather River basin. The City of Yuba City diverts water from the Feather River immediately upstream from the Yuba River confluence with the Feather River–RM 028. Butte County acts as a wholesaler of SWP water to municipal agencies within the county.

For modeling purposes, Butte County's SWP water is available to Thermalito Irrigation District (ID) (DU U_11_NU1), Cal Water–Oroville (DU U_12_13_NU1), and the City of Yuba City (DU U_16_PU). Cal Water–Oroville purchases water from Pacific Gas and Electric (PG&E), which is delivered from the West Branch of the Feather River via the Miocene Canal, and diverts SWP water, through Butte County, from the Thermalito Power Canal. Thermalito ID holds water rights associated with Concow Reservoir. Under an agreement with the State, the reservoir is kept full during the summer months for fishery purposes. Water released in the fall, winter, and spring is stored in Lake Oroville and re-released in the summer to meet Thermalito ID demands.

DWR has signed contracts/agreements with districts in the Feather River Service Area (FRSA). These districts include Western Canal WD, Joint Board WD, Plumas Mutual Water Company (MWC), Garden Highway MWC, Oswald WD, and Tudor MWC. Western Canal WD and the Joint Board WD divert from the Thermalito Afterbay. Points of diversion from the other WDs are based on SWP settlement contracts (DWR, 1997a). FRSA is represented in SacWAM by portions of WBAs 11, 12, and 16.

In addition to WDs, many individual agricultural water users hold water rights senior to SWP for Feather River water. Data on water entitlements for the Feather River were collected by DWR as part of the Feather River Trial Distribution Program, and published in Bulletin 140 (DWR, 1965). The net irrigable area of lands of riparian and appropriative water rights was estimated to be approximately 30,000 acres. For SacWAM, surface water diversions to these individuals are based on estimates of irrigated riparian lands, beneficial use, and appropriative water rights (Sergent, 2008); and on Bulletin 168 (DWR, 1978).

3.8.2.2 *North Bay Aqueduct*

The North Bay Aqueduct is part of the SWP, delivering water to Solano County Water Agency (WA) and Napa County FC&WCD, which are both long-term water contractors. Under agreements with Solano County WA, water from the North Bay Aqueduct is delivered to the cities of Benicia, Vallejo, Fairfield, and Vacaville. The cities of Suisun, Rio Vista, and Dixon all have contract entitlements to water from the North Bay Aqueduct but currently do not have facilities to receive this supply. Under agreements with Napa County FC&WCD, the cities of Calistoga, Napa, St. Helena, and American Canyon, and the Town of

Yountville receive SWP water from an extension of the North Bay Aqueduct. In addition, SWP delivers water right water through the North Bay Aqueduct.

SacWAM represents the North Bay Aqueduct as a diversion from Cache Slough. Points of diversion are based on data ptresented in the SWP Handbook (DWR, 1997a). Except for the City of Vacaville (DU U_20_25_PU), all deliveries from the North Bay Aqueduct are exports from the model domain. Three demand sites represent the export demands for Solano and Napa. Multiple arcs to each demand site differentiate between types of SWP water (Table A and Article 21) and water right water (Vacaville Permit Water and Settlement Water).

3.8.3 Non-Project Diversions

In the context of SacWAM, non-project diversions include all surface water diversions that are not part of the CVP or SWP. However, non-project diversions include Federal projects other than the CVP.

3.8.3.1 *Diversions from Sacramento River*

Major diverters of non-project water along the Sacramento River include Llano Seco Rancho, and the Cities of Sacramento and West Sacramento. Additionally, Sacramento County WA and East Bay Municipal Utility District (EBMUD) divert non-project water as part of the Freeport Regional Water Project. In the future, the Cities of Davis and Woodland are planning to divert non-project water as part of the Davis-Woodland Project.

Non-project diversions from the Sacramento River other than those described above are not well defined, and records of their historical diversions are incomplete or unavailable. DWR's county land use surveys (DWR, 1994a-b, 1995a-b, 1996, 1997b, 1998a-c, 1999a-b, 2000a) were used to identify land that was contiguous with the Sacramento River, and within three miles of the river centerline. From the county land use survey information, a subset of these lands was identified as cropland that is irrigated by surface water or mixed surface water and groundwater and lies outside any WDs or IDs. Model diversion arcs to these non-project diverters can represent multiple real-world diversion locations.

3.8.3.2 *Diversions from Feather River*

SacWAM represents the major imports and exports of water from the upper Feather River watershed above Lake Oroville. These include the export of water from the West Branch Feather River at the Hendricks Diversion Dam as part of PG&E's DeSabla-Centerville Project (FERC No. 803), and the import of water from Slate Creek as part of South Feather Water and Power Agency's South Feather Hydroelectric Project (FERC No. 2088). Water diversions for use within the Feather watershed include West Branch Feather River diversion in to the Miocene Canal and South Feather Water and Power Agency's diversions in to the Oroville-Wyandotte Canal and in to the Miners Ranch Canal.

Major diversions from the Feather River below Oroville consist of water right holders who have signed settlement agreements with DWR (see section 3.8.2.1). In addition, there are many minor appropriative and riparian water right holders who divert water from both the left and right banks of the river. For SacWAM, these minor diversions were determined using detailed diversion data published in Bulletin 168 (DWR, 1978), estimates of irrigated riparian lands and beneficial use, eWRIMS database of appropriative water rights, and from personal communication with DWR (Sergent, 2008).

3.8.3.3 *Diversions from Yuba River*

The Yuba River has been extensively developed for hydropower generation and water supply. Development in the upper watersheds of the North, Middle and South Yuba rivers and Deer Creek include: parts of South Feather Water and Power Agency's South Feather Hydroelectric Project (FERC 2088), Yuba County WA's Yuba River Development Project (FERC No. 2246), Nevada ID's Yuba-Bear Hydroelectric Project (FERC No. 2266), PG&E's Drum-Spaulding Project (FERC No. 2310), and USACE's Englebright and Daguerre Point dams. SacWAM represents the major diversion and export facilities associated with these projects, including Slate Creek Tunnel, Lohman and Camptonville tunnels, Milton-Bowman Tunnel, Bowman-Spaulding Conduit, and the South Yuba and Drum canals. Demand sites within these upper watersheds are limited to Nevada ID's Deer Creek unit, which includes irrigated agriculture and urban water supplies to Grass Valley and Nevada City.

As part of the Yuba River Development Project, Yuba County WA delivers water to its member units at Daguerre Point Dam located at RM 11. Water is diverted to irrigate lands both north and south of the river. Additionally, Browns Valley ID diverts water at its pumping plant located approximately two miles upstream at RM 13. SacWAM includes three transmission links for these non-project diversions from the lower Yuba River.

Dry Creek joins the Yuba River from the north, approximately two miles upstream from Daguerre Point Dam. Flows in Dry Creek are regulated by Browns Valley ID's operation of Merle Collins Reservoir and Virginia Ranch Dam. The district supplements Yuba River water with diversions below Merle Collins Reservoir. SacWAM aggregates these diversions to a single point of diversion.

3.8.3.4 *Diversions from Bear River*

The Bear River watershed upstream from Camp Far West Reservoir includes storage and diversion facilities owned and operated by Nevada ID, Placer County WA, and PG&E. The SacWAM schematic includes inflows from PG&E's Drum Canal and exports to PG&E's Bear River Canal and Placer County WA's Lower Boardman Canal. SacWAM also represents Nevada ID diversions from Combie Canal.

Water is released from Camp Far West Reservoir for power generation, irrigation, and to meet downstream flow requirements (see section 7.2.3.6). South Sutter WD operates a diversion dam at RM 17, approximately one mile downstream from Camp Far West Dam, to irrigate lands served by Camp Far West ID and South Sutter WD. SacWAM uses two transmission links to represent left bank and right bank diversions at the diversion dam.

3.8.3.5 *Diversions from American River*

SacWAM represents the upper American River watersheds of the North Fork, Middle Fork, and South Fork. The schematic portrays the export of water from the North Fork American River watershed to the Bear River watershed as part of PG&E's Drum-Spaulding Project. The schematic also includes diversions associated with Placer County WA's Middle Fork Project, Sacramento Municipal Utility District's (SMUD) American River Project, and El Dorado ID's South Fork Project. There is a single demand site in the upper watershed representing Georgetown PUD. Additionally, SacWAM represents the Placer County WA diversion upstream from Folsom at the Auburn Dam site and El Dorado ID's diversion from the El Dorado Canal.

There are no significant agricultural diversions from Folsom Lake and the lower American River. There are, however, four municipalities that divert water from Folsom Lake (City of Roseville, San Juan WD, City of Folsom, and El Dorado ID). Additionally, Aerojet, Folsom State Prison, and State Parks receive water from Folsom Lake. As part of the CVP, water is diverted from Lake Natoma into the Folsom South Canal. From the canal, project water is delivered to Golden State WA, and Sacramento Municipal Utility District's Rancho Seco Power Plant. On the lower American River, there are two diversions to the Carmichael WD and the City of Sacramento. In SacWAM these diversions are represented by diversion arcs to water treatment plants and transmission links connecting the diversion arc to individual demand units.

3.8.3.6 *Diversions from Stony Creek*

The Orland Project, centered on Stony Creek, is one of the oldest Federal Reclamation projects in the country. Water was delivered to the first farm units at the beginning of the 1910 growing season. The main elements of the project include East Park Dam, Stony Gorge Dam, Rainbow Diversion Dam and East Park Feeder Canal, South Diversion Intake and South Canal, and Northside Diversion Dam and North Canal. Black Butte Dam, constructed by the U.S. Army Corps of Engineers (USACE), is an authorized facility of CVP. The CVP and the Orland Project are separate projects with separate water rights.

3.8.3.7 *Diversions from Cache Creek*

Clear Lake is the dominant feature within the Cache Creek watershed. Releases from the lake for agricultural water supply are supplemented by releases from Indian Valley Reservoir located on the North Fork Cache Creek. SacWAM represents minor withdrawals from Clear Lake to the surrounding communities (U_CLLPT). SacWAM represents all agricultural water use by a single diversion at the Capay Diversion Dam at RM 30, where water is delivered to the Yolo County FC&WCD service area (A_20_25_NA1).

3.8.3.8 *Diversions from Putah Creek*

The Solano Project was constructed from 1953 to 1959 by Reclamation to provide irrigation water to approximately 96,000 acres of land located in Solano County. The project also furnishes M&I water to the major cities of Solano County. Project facilities include Lake Berryessa and Monticello Dam, Putah Diversion Dam, Putah South Canal and canal distribution system, and a small terminal reservoir (Solano County WA, 2011). Water released from Monticello Dam is diverted at the Putah Diversion Dam located approximately six miles downstream. Water is subsequently conveyed to its end users via the Putah South Canal. In addition to the Solano Project, there are minor diversions in the Putah Creek watershed under both riparian and appropriative water rights. These include diversions by UC Davis from the South Fork of Putah Creek. These minor diversions are not represented in SacWAM.

3.8.3.9 *Diversions from Cosumnes River*

The Cosumnes River watershed remains largely unimpaired by development except for the former Sly Park Unit of the CVP that was transferred to El Dorado ID in 2003. SacWAM represents Jenkinson Lake and associated imports from Camp Creek and exports through the Sly Park-Camino Conduit to the El Dorado ID service area. El Dorado ID diversions into the Crawford Ditch from the North Fork Cosumnes River are not represented. Below the USGS gauge at Michigan Bar, SacWAM represents a single point of diversion - to the community of Rancho Murieta (DU U_60N_NU2) at Granlees Dam. There are many small diversions along the lower Cosumnes River, typically consisting of small pumps that divert less than 1 cfs. SWRCB records show there are approximately 133 active water rights applicants and licenses, representing an annual entitlement of up to 5,700 acre-ft in the lower Cosumnes River watershed. These diversions are not currently represented in SacWAM.

3.8.3.10 *Diversions from Dry Creek*

Dry Creek, located south of the Cosumnes watershed, joins the Mokelumne River near the confluence with Cosumnes River. Flows in Dry Creek are partially regulated by Lake Amador, located on Jackson Creek. SacWAM represents the lake and the water supply from Pardee Reservoir under an agreement between Jackson Valley ID and EBMUD. SacWAM represents diversions from Lake Amador to supply the irrigation district (A_60N_NA1), but does not represent any other diversions in the Dry Creek watershed.

3.8.3.11 *Diversions from Mokelumne River*

The Mokelumne River watershed can be divided into upper and lower watersheds by the USGS gage at Mokelumne Hill (11319500) located near Highway 49. The upper watershed includes the North Fork, Middle Fork, and South Fork, and 8 miles of the main stem of the Mokelumne River.

North Fork

PG&E owns and operates the Mokelumne Hydroelectric Project (FERC No. 137) on the North Fork Mokelumne River. The project consists of seven storage reservoirs and associated diversions and powerhouses. SacWAM combines the reservoirs, principally Lower Bear and Salt Springs reservoirs, in to a single storage unit. Downstream diversions by Amador Water Agency to serve local communities are aggregated to a single point of diversions in the model (DU AMADR).

Middle and South Forks

SacWAM represents the Middle Fork and South Mokelumne River as two fixed timeseries of inflows. The model aggregates diversions by Calaveras County WD and Calaveras PUD to a single point of diversion downstream from the confluence of the two forks. The diversion supplies Mokelumne Hill and other rural communities (DU CCWD and CPUD).

Main Stem

EBMUD owns and operates Pardee and Camache reservoirs located on the main stem of the Mokelumne River in the lower watershed. From Pardee, the district diverts water in to the Mokelumne Aqueduct to convey water to its service district in the San Francisoo Bay Area. SacWAM simulates diversions to the Mokelumne Aqueduct and also water delivers from Pardee Reservoir to Lake Amador.

Water right holders on the lower Mokelumne River below Camanche Dam include North San Joaquin WCD, Woodbridge ID, and minor riparian and appropriative water right holders. SacWAM represents separate diversions to these entities. Diversions to North San Joaquin WCD (DU A_60N_NA3) are represented as a single diversion at RM 51. Minor diversions to individual water right holders (DU A_60N_NA5) are located at two points, upstream and downstream from the Woodbridge Diversion Dam. Lastly, SacWAM represents diversions to Woodbridge ID (DU A_60N_NA4) and district wholesale agreements with the City of Lodi (U_60N_NU1) and the City of Stockton (U_60S_NU1) using three transmission links located at the diversion dam at RM 37.

3.8.3.12 *Diversions from Calaveras River*

The Calaveras River is divided into upper and lower reaches by New Hogan Reservoir located at RM 45, which was built by USACE for water supply and flood control purposes. There is little development above the dam. Approximately 20 miles below the dam, the river divides at the Bellota Weir in to Mormon Slough and the old Calaveras River channel. There are many irrigation diversions along both of these waterways.

Water stored in New Hogan Reservoir is shared between Stockton East WD and Calaveras County WD. From New Hogan Dam to Bellota Weir at RM 25, SacWAM includes only a single diversion - at RM 43 to the unincorporated area of Jenny Lind (DU U_JLIND). All other diversions are aggregated and represented in the model by two transmission links located at Bellota Weir. The first transmission link supplies irrigation water to Stockton East WD and riparian diverters in Claveras County (DU A_60S_PA). The second represents the raw water supply to the Stockton East WD water treatment plant that supplies the City of Stockton (U_60S_NU1).

3.8.3.13 *Diversions from Minor Streams and Creeks*

Points of diversion for minor tributaries to the Sacramento River were identified from a variety of sources, including SWRCB's eWRIMS database (SWRCB, 2014), annual bulletins published by DWR and its predecessors[5], and aerial imagery. Typically, on minor creeks, diversions for agricultural water supply are aggregated to a single point in SacWAM located at the largest diversion structure, where one exists.

3.8.3.14 *Diversions from the Sacramento-San Joaquin Delta*

SacWAM's representation of agricultural water use in the Delta and associated surface water diversions and return flows is highly conceptual and represents a balance between Delta channel accretions and channel depletions.

Channel accretions result from rainfall-runoff, excess irrigation water, and seepage from Delta islands. Excess water is pumped from the Delta islands back into the Delta. Channel depletions primarily consist of irrigation and leach water. Net channel depletions are the difference between total diversions and total drainage or return flows. In SacWAM, the Delta is divided into seven Delta subregions, each represented by a single diversion and and a single return flow. These subregions are illustrated in Figure 3-3, and are identical to regions identified by DWR for modeling purposes. SacWAM incorporates two options for quantifying the diversions and return flows, as follows:

[5] Bulletin 23, published continuously between 1930 and 1965 (DWR, 1924-1962), contains data for monthly diversions, streamflows, return flows, water use, and salinity in the Sacramento River and San Joaquin watersheds. The series was discontinued in 1965, following the publication of Bulletin 23-62. Bulletin 130 superseded Bulletin 23 and presented hydrologic data in five appendices covering the entire State. The bulletin was published annually from 1963 through 1975 and was last published in 1988 (DWR, 1963-1975, 1988). Bulletin 130 superseded Bulletin 23, and presents hydrologic data in five appendices covering the entire State. The bulletin was published annually from 1963 through 1975 and was last published in 1988 (DWR, 1963-1975, 1988).

- For consistency with DWR's planning model CalSim II and the agency's Delta hydrodynamic model DSM2, SacWAM Delta channel diversions and return flows may be read from a CSV file containing monthly timeseries developed by DWR for CalSim.
- SacWAM includes 7 watershed objects to represent the Delta subregions with associated transmission links and runoff-infiltration arcs.

Though use of SacWAM watershed objects may provide a better estimate of crop consumptive use, the default option for running SacWAM is to use DWR-based flows to provide consistency with other planning processes.

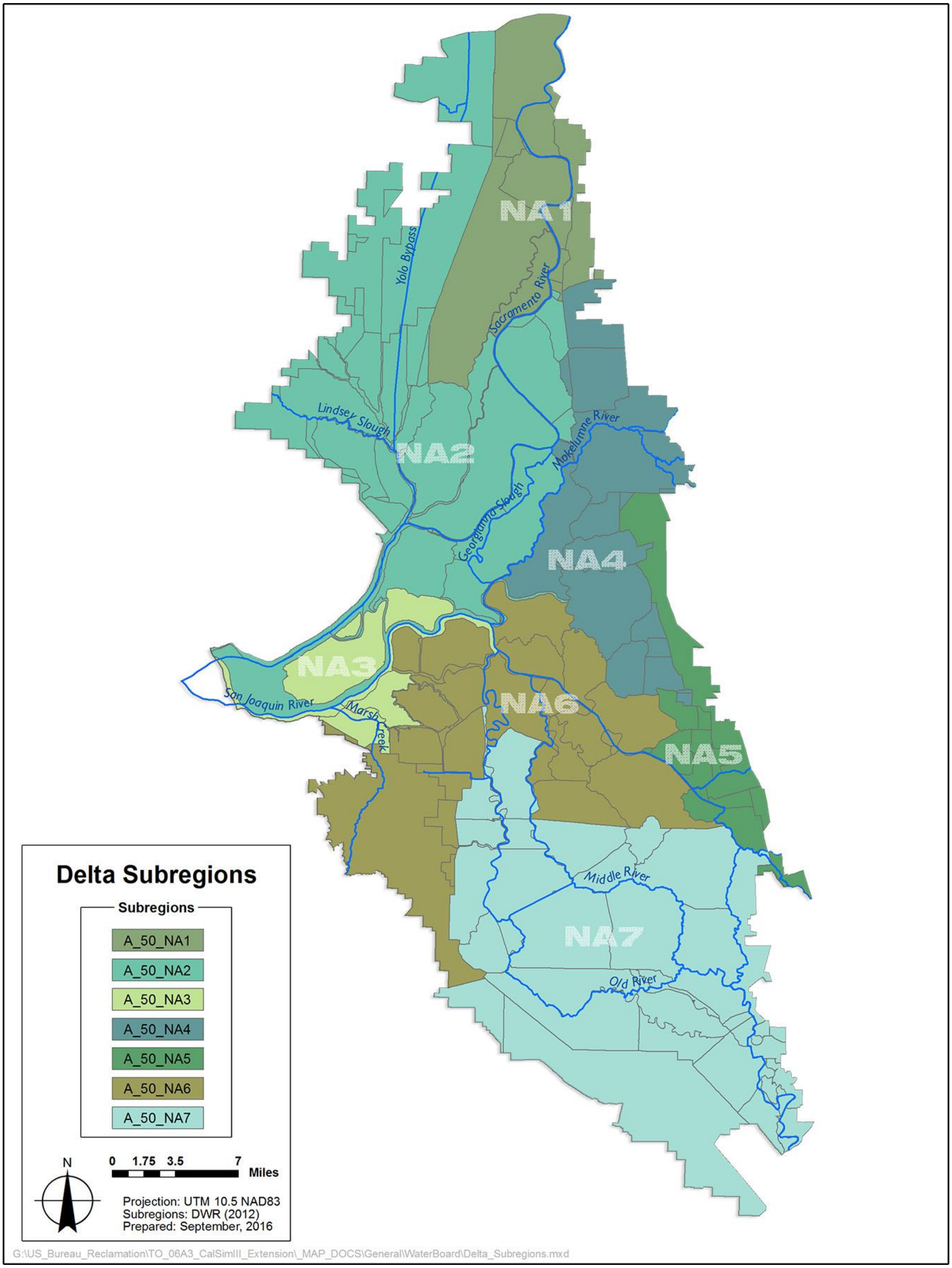


Figure 3-3. Delta Subregions

Table 3-6. Surface Water Diversions by Agricultural Demand Unit

Demand Unit	Surface Diversion(s)
CVP North of Delta Water Service Contracts	
A_02_PA	Whiskeytown Reservoir
A_03_PA	Sacramento River RM 294
A_04_06_PA1	Tehama-Colusa Canal CM 001
A_04_06_PA2	Tehama-Colusa Canal CM 022
A_07_PA	Tehama-Colusa Canal CM 036 & CM 081
A_08_PA	Colusa Basin Drain CM 028; Glenn-Colusa Canal CM 065
A_16_PA	Feather River RM 021
A_21_PA	Knights Landing Ridge Cut CM 005
CVP Sacramento River Settlement Contracts	
A_02_SA	Sacramento River RM 296
A_03_SA	Sacramento River RM 289
A_08_SA2	Colusa Basin Drain CM 041; Glenn-Colusa Canal CM 027
A_09_SA1	Sacramento River RM 196; Butte Creek RM 045
A_08_SA1	Sacramento River RM 159 & RM 178; Colusa Basin Drain CM 049
A_08_SA3	Sacramento River RM 109 & RM 121; Colusa Basin Drain CM 028
A_09_SA2	Sacramento River RM 162; Butte Creek RM 012
A_21_SA	Sacramento River RMs 074 & 083; Yolo Bypass CM 023
A_22_SA1	Sacramento River RMs 078 082; Auburn Ravine RM 000
Other Federal Project Diverters	
A_04_06_PA3	Stony Creek RM 021 & RM 026 (Orland Project)
A_20_25_PA	Putah South Canal CM 003 (Solano Project)
SWP Feather River Service Area	
A_11_SA1	Thermalito Reservoir Afterbay
A_11_SA2	Thermalito Reservoir Afterbay; Joint Board Canal CM 000
A_11_SA3	Joint Board Canal CM 000
A_11_SA4	Feather River RM 039; Joint Board Canal CM 000
A_12_13_SA	Feather River RM 059
A_14_15N_SA	Feather River RM 059
A_15S_SA	Feather River RM 028
A_16_SA	Feather River RM 014
A_17_SA	Feather River RM 014
A_22_SA2	Feather River RM 012
In-Delta Diverters	
A_50_NA1	Sacramento River RM 041
A_50_NA2	Sacramento River RM 017
A_50_NA3	Sacramento River RM 000
A_50_NA4	Mokelumne River RM 004
A_50_NA5	San Joaquin River RM 026
A_50_NA6	San Joaquin River RM 013
A_50_NA7	Old River RM 027
Non-Project Diverters	
A_24_NA2	Auburn Ravine RM 010
A_24_NA1	Auburn Ravine RM 024; Rock Creek Reservoir; Lake Combie
A_23_NA	Bear River RM 017; Auburn Ravine RM 006
A_10_NA	Butte Creek RM 036; West Branch Feather RM 015
A_20_25_NA1	Cache Creek RM 030
A_20_25_NA2	Cache Slough RM 005
A_60S_PA	Calaveras River RM 026; Farmington Reservoir
A_60N_NA2	Folsom South Canal CM 015

Table 3-6. Surface Water Diversions by Agricultural Demand Unit contd.

Demand Unit	Surface Diversion(s)
A_14_15N_NA3	French Dry Creek RM 006; Yuba River RM 013
A_60N_NA1	Lake Amador
A_24_NA3	Lower Boardman Canal CM 049
A_60N_NA4	Mokelumne River RM 035
A_60N_NA3	Mokelumne River RM 050
A_60N_NA5	Mokelumne River RM 050
A_12_13_NA	Oroville Wyandotte Canal CM 000; Miners Ranch Reservoir
A_02_NA	Sacramento River RM 281; Cottonwood Creek RM 009
A_03_NA	Sacramento River RM 273; Battle Creek RM 006; Cow Creek RM 014
A_04_06_NA	Sacramento River RM 224; Thomes Creek RM 012
A_05_NA	Sacramento River RM 240; Antelope Creek RM 010; Mill Creek RM 006; Deer Creek RM 005 & RM 010
A_08_NA	Sacramento River RM 146
A_09_NA	Sacramento River RM 185 & RM 196; Butte Creek RM 045
A_18_19_NA	Sacramento River RM 136; Sutter Bypass CM 034
A_18_19_SA	Sacramento River RMs 115, 121, & 136
A_21_NA	Sacramento River RM 081
A_22_NA	Sacramento River RM 075
A_61N_NA3	San Joaquin River RM 070
A_61N_NA2	Stanislaus River RM 030
A_61N_PA	Stanislaus River RM 059
A_17_NA	Sutter Bypass CM 014
A_11_NA	Sutter Bypass CM 028
A_16_NA	Sutter Bypass CM 028
A_14_15N_NA2	Yuba River RM 011
A_15S_NA	Yuba River RM 011

Notes:
[1] A_04_06_NA includes some minor CVP settlement contractors.
Key: CM=Canal Mile; CVP=Central Valley Project; RM=River Mile; SWP=State Water Project.

Table 3-7. Surface Water Diversions by Urban Demand Unit

Demand Unit	Surface Diversion(s)
CVP North of Delta Water Service Contracts	
U_02_PU	Whiskeytown Reservoir (Centerville CSD, Clear Creek CSD,Keswick CSA, Shasta CSD)
U_03_PU	Shasta Lake; Sacramento River RM 294; Whiskeytown Reservoir (City of Redding, Bella Vista WD, others)
U_21_PU	Sacramento River RM 065 (West Sacramento)
U_26_PU1	Folsom Lake (City of Roseville)
U_26_PU2	Folsom Lake (San Juan WD)
U_26_PU3	Folsom Lake (City of Folsom/Folsom Prison)
U_26_PU4	Sacramento River RM 054, RM 062 (Sacramento County WA)
U_26_PU5	Folsom South Canal CM 003 (Golden State WC)
U_60N_PU	Folsom South Canal CM 025 (SMUD)
U_CCWD	Sacramento River RM 000; Contra Costa Canal CM 019 (Contra Costa WD)
U_EBMUD	Sacramento River RM 050 (EBMUD)
U_ELDID	Folsom Lake (El Dorado ID)
CVP Sacramento River Settlement Contracts	
U_02_SU	Sacramento River RM 296 (City of Redding)
U_03_SU	Sacramento River RM 296 (City of Redding)
Other Federal Projects	
U_20_25_PU	Putah South Canal CM 013 (Solano Project - City of Vacaville)
U_FVTB	Putah South Canal CMs 013 & 017 (Cities of Benicia, Fairfield, Suisun, Vacaville, and Vallejo)
SWP Settlement and Long-Term Table A Contractors	
U_11_NU1	Thermalito Power Canal (Thermalito ID)
U_12_13_NU1	West Branch Feather RM 015; Thermalito Power Canal (CalWater-Oroville); Palermo Canal
U_16_PU	Feather River RM 031 (Yuba City)
U_FVTB	North Bay Aqueduct CM 009 (Cities of Benicia, Fairfield, Vacaville, and Vallejo)
U_20_25_PU	North Bay Aqueduct CM 011 (City of Vacaville)
U_NAPA	North Bay Aqueduct RM 027 (Napa County FC&WCD)
Non-Project Diverters	
U_12_13_NU2	Miners Ranch Reservoir (South Feather Water and Power Agency)
U_14_15N_NU	Yuba River RM 003 (City of Marysville)
U_20_25_NU	Sacramento River RM 074 (Cities of Davis and Woodland)
U_24_NU1	Wise Canal CM 004; Lower Boardman Canal CM 038 (Placer County WA - Zone 1, Nevada ID)
U_24_NU2	South Canal CM 004; Auburn Tunnel CM 002 (Placer County WA - Zone 1)
U_26_NU1	American River RM 007 (City of Sacramento wholesale agreements)
U_26_NU2	American River RM 017 (Carmichael WD)
U_26_NU3	Sacramento River RM 062; American River RM 007 (City of Sacramento)
U_26_NU4	American River RM 007 (City of Sacramento)
U_26_NU5	Folsom Reservoir (Aerojet)
U_26_NU6	Folsom Reservoir (Parks and Recreation)
U_60N_NU2	Cosumnes River RM 033 (Rancho Murieta)
U_60S_NU1	Calaveras River RM 026; Mokelumne River RM 035; San Joaquin River RM 028; Farmington Reservoir (City of Stockton)
U_ANTOC	Contra Costa Canal CM 007; San Joaquin River RM 006 (City of Antioch)
U_CLLPT	Clear Lake (lakeshore communities)
U_EBMUD	Mokelumne Aqueduct CM 057 (East Bay MUD)
U_JLIND	Calaveras River RM 043 (Jenny Lind)
U_PCWA3	Lower Boardman Canal CM 010 (Placer County WA - Zone 3)

Key: CM=Canal Mile; CSA=County Service Area; CSD=Community Service District; CVP=Central Valley Project; EBMUD=East Bay Municipal Utility District; FC&WCD=Flood Control and Water Conservation District; ID=Irrigation District; RM=River Mile; SMUD = Sacramento Municipal Utility District; SWP=State Water Project; WA=Water Agency; WC=Water Company; WD=Water District.

Table 3-8. Surface Water Diversions by Refuge Demand Unit

Demand Unit	Surface Diversion(s)
R_08_PR	Glenn-Colusa Canal CMs 027 & 056
R_09_PR	Sacramento River RM 196
R_11_PR	Thermalito Reservoir
R_17_NR	Butte Creek RM 012
R_17_PR1	Thermalito Reservoir
R_17_PR2	Feather River RM 039

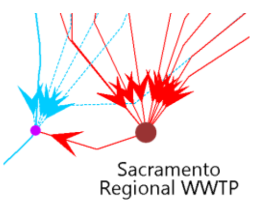
Key: CM=Canal Mile; RM=River Mile.

3.9 Water Treatment Plants

The WEAP software does not have an object for representing water treatment plants. However, SacWAM does represent several water treatment plants indirectly using a combination of diversion arcs and transmission links. The diversion arc represents the river intake to the water treatment plant; the transmission links connect the diversion to the urban demand unit and represent the distribution system downstream from the water treatment plant. Water treatment plants are represented in this manner where they serve more than one demand unit. Examples include the City of Redding's Foothill WTP, City of Sacramento's Sacramento WTP and Fairbairn WTP, Sacramento County WA's Vineyard WTP, El Dorado ID's El Dorado Hills WTP, City of Roseville's WTP, San Juan WD Petersen WTP, and Carmichael WD's Bajamont WTP.

3.10 Wastewater Treatment Plants

SacWAM defines wastewater return flows for each urban demand unit. Treated wastewater from large



urban centers, with dedicated or regional wastewater treatment plants, may be discharged to surface waters. However, in most rural areas and smaller communities, wastewater typically is discharged to private septic systems or evaporation ponds, which recharge the underlying groundwater aquifer. Wastewater treatment plants are explicitly represented in SacWAM in cases where they have a capacity greater than 5 million gallons per day (mgd) and discharge treated water to a surface water body. WEAP "Wastewater Treatment Plant" objects are represented by a brown circle.

Wastewater treatment plants that discharge to surface waters were identified from the NPDES permits database (EPA, 2014). Those represented in SacWAM are listed in Table 3-9, together with their discharge permit capacity and average dry weather discharge rate, where available.

Table 3-9. Wastewater Treatment Plants Represented in SacWAM

	Facility Data		Surface Water Discharge			
Facility	Operator	Treated Wastewater[1] (mgd)	Receiving Waters	SacWAM River Mile	Permit Capacity[2] (mgd)	Fraction of Wastewater Discharged[3]
Anderson WPCP	City of Anderson	1.4	Sacramento River	281	2.0	100%
Auburn WWTP	City of Auburn	–	Auburn Ravine	027	1.7	100%
Chico WPCP	City of Chico	7.0	Sacramento River	195	9.0	100%
Clear Creek WWTP	City of Redding	9.6	Sacramento River	287	8.8	100%
Cottonwood WWTP	Shasta CSA #17	0.3	Cottonwood Creek	281	0.4	100%
Dry Creek WWTP	City of Roseville	10.0	Dry Creek	012	18.0	100%
Easterly WWTP	City of Vacaville	14.9	Alamo Creek	005 (Cache Slough)	6.9	100%
Lake California WWTP	Rio Alto WD	0.2	Sacramento River	281	0.6	100%
Lincoln WWTP	City of Lincoln	2.8	Auburn Ravine	002 (Natomas Cross Canal)	1.4	100%
Linda WWTP	Linda WD	1.3	Feather River	025	6.7	100%
Oroville WWTP	Sewage Commission Oroville Region	3.0	Feather River	063	6.5	100%
Red Bluff WWTP	City of Red Bluff	1.4	Sacramento River	240	2.5	100%
Sacramento Regional WWTP	Sacramento Regional County Sanitation District	142.2	Sacramento River	048	181.0	100%
Stillwater Regional WWTP	City of Redding	4.0	Sacramento River	281	4.0	100%
Stockton Regional Wastewater Control Facility	City of Stockton	28.0	San Joaquin River	042	55.0	100%
White Slough WPCF	City of Lodi	6.3	White Slough	028 (San Joaquin River)	8.5	100%
Willows WWTP	City of Willows	–	Drain Ditch	049 (Colusa Basin Drain)	1.1	100%
Woodland WPCF	City of Woodland	5.6	Tule Canal	032 (Yolo Bypass)	7.8	100%
Yuba City WWTP	City of Yuba City	8.9	Feather River	028	10.5	75%

Notes:

[1] Estimated dry weather flow for 2010. Values were obtained from 2010 urban water management plans, wastewater system master plans, and other sources. The symbol "–" indicates that no historical data were collected as part of the CalSim Hydrology Development Project. One mgd is equivalent to 1,120 acre-feet per year.

[2] Source: Permit Compliance System (PCS) database (Environmental Protection Agency, 2014), a computerized management system which contains data on National Pollutant Discharge Elimination System (NPDES) permit holding facilities. http://oaspub.epa.gov/enviro/ef_home2.water.

[3] The fraction of treated water that is discharged to surface water is assumed equal to 100 percent unless specific information (including reuse) is published in 2010 urban water management plans. For modeling purposes, treated wastewater not discharged to surface waters is assumed to percolate to groundwater.

Key: CSA=community service area; mgd=million gallons per day; WD=water district; WPCF=water pollution control facility; WPCP=water pollution control plant; WWTP=wastewater treatment plant.

3.11 Return Flows

In SacWAM, WEAP's return flow arcs are associated with urban demand units and represent discharge of treated wastewater to either a surface body or the underlying groundwater aquifer. Table 3-9 lists the major wastewater return flows to surface water. Twenty-two urban demand units discharge all treated water to groundwater; in some instances to two or more groundwater basins. Three demand units discharge treated water to a mix of surface water and groundwater. Thirty-four demand units discharge all treated wastewater water to a surface water body. In the Sacramento metropolitan area, return flows from nine demand units are aggregated at the the Sacramento Regional WWTP and subsequently discharge to the Sacarmento River below the Freeport gauge.

Demand unit NIDDC_NA is an exception in the SacWAM schematic, being an agricultural demand represented by a WEAP demand site object. Irrigation return flows are represented using a Return Flow arc, rather than a Runoff/Infiltration arc.

3.12 Flow Requirements

WEAP “Instream Flow Requirement” objects are represented by a purple circle and cross. Three types of flow requirements are represented in the SacWAM schematic. They are distinguished by their prefix as follows:

- REG: Flow requirements that are regulatory in nature.
- OPS: Flow requirements that are used to drive upstreamstorage regulation or diversions through canals and tunnels.
- SWRCB: Potential new regulatory flow requirements where the flow requirement is specified as a fraction of the unimpaired flow.

Flow requirements are discussed in greater details in Sections 6.1.3 and 7.2.3. Table 3-11 lists the regulatory instream flow requirements included in the schematic. Table 3-10 lists potential instream flow requirements that may be implemented as part of the revised Bay-Delta Plan.

3.13 Run of River Hydro Plants

WEAP includes “Run of River Hydro” objects to simulate hydropower generation. However, these objects are not used in SacWAM.

Table 3-10. Instream Flow Requirements Represented in SacWAM

Name	River	Description
REG American IFR	American River	Lower American River Flow Management Standard
REG D893 H St	American River	1958 WRD-893
REG Bear R blw CFW	Bear River	1994 Settlement Agreement between DWR, South Sutter WD, and Camp Far West ID.
REG CA Health and Safety	California Aqueduct	Minimum export at Banks Pumping Plant to meet Health and Safety flow requirements
REG Clear Ck IFR	Clear Creek	Combination fo 1960 MOA between DWR and CDFG, (b)2 actions, and 2009 NMFS BiOp
REG DMC Health and Safety	Delta-Mendota Canal	Minimum export at Jones Pumping Plant to meet Heath and Safety flow requirements
REG HighFlow Channel	Feather River	1986 MOU between CDFG and DWR
REG LowFlowChannel	Feather River	1986 MOU between CDFG and DWR
REG Verona	Feather River	1986 MOU between CDFG and DWR
REG Kellog Creek IFR	Kellogg Creek	SWRCB D-1629: Los Vaqueros Project
REG blw Camanche	Mokelumne River	1998 Joint Settlement Agreement and FERC license for the Lower Mokelumne Hydroelectric Project (FERC No. 2916).
REG Below Woodbridge Diversion Dam	Mokelumne River	1998 Joint Settlement Agreement and FERC license for the Lower Mokelumne Hydroelectric Project (FERC No. 2916).
REG X2	Net Delta Outflow	Outflow to meet D-1641 X2 requirements and USFWS 2009 BO Fall X2 requirement
REG MRDO	Net Delta Outflow	Outflow to meet D-1641 flow requirements
REG Below PG&E Dams	NF Mokelumne River	2001 FERC license for the North Fork Mokelumne Project (FERC No. 137)
REG Below Electra Powerhouse	NF Mokelumne River	2001 FERC license for the North Fork Mokelumne Project (FERC No. 137)
REG Below Electra Dam	NF Mokelumne River	2001 FERC license for the North Fork Mokelumne Project (FERC No. 137)
REG Lower Putah Diversion Dam	Putah Creek	2000 Putah Creek Accord/Settlement Agreement flow requirements below Putah Diversion Dam.
REG Lower Putah I80 Bridge	Putah Creek	2000 Putah Creek Accord/Settlement Agreement flow requirements at I-80 road bridge
REG Delta Salinity GModel	Sacramento River	Outflow to meet D-1641 flow requirements using G-model. Not active.
REG Sac at Rio Vista	Sacramento River	D-1641 flow requirement
REG Sac bw Keswick	Sacramento River	Combination of CVPIA (b)2 actions, WR90-5, and 2009 NMFS BiOp.
REG Vernalis	San Joaquin River	Not active
REG Trinity IFR	Trinity River	2001 Trinity River Record of Decision
REG Yuba River nr Marysville	Yuba River	Lower Yuba River Accord/SWRCB Revised WRD-1644.
REG Yuba River nr Smartville	Yuba River	Lower Yuba River Accord/SWRCB Revised WRD-1644.

Key: BiOp=Biological Opinion; CVPIA=Central Valley Improvement Act; DWR=Department of Water Resources; FERC=Federal Energy Regulatory Commision; ID=Irrigation District; MOU=Memorandum of Understanding; NF=North Fork; WD=Water District; WRD=Water Right Decision; SWRCB=State Water Resources Control Board;

Table 3-11. State Water Board Potential Instream Flow Requirements Represented in SacWAM

Name	River	Location
SWRCB American River	American River	Confluence with Sacramento River
SWRCB Antelope Creek	Antelope Creek	Confluence with Sacramento River
SWRCB Battle Creek	Battle Creek	Confluence with Sacramento River
SWRCB Bear River	Bear River	Confluence with Sacramento River
SWRCB Big Chico	Big Chico Creek	Confluence with Sacramento River
SWRCB Black Butte	Stony Creek	Confluence with Sacramento River
SWRCB Butte Creek	Butte Creek	Confluence with Butte Slough
SWRCB Cache Creek	Cache Creek	Confluence with Yolo Bypass
SWRCB Calaveras River	Calaveras River	Confluence with San Joaquin River
SWRCB Camanche	Mokelumne River	Below Camanche Dam
SWRCB Camp Far West	Bear River	Below Camp Far West Dam
SWRCB Clear Creek	Clear Creek	Confluence with Sacramento River
SWRCB Clear Lake	Cache Creek	Below Cache Creek Dam
SWRCB Cosumnes River	Cosumnes River	Confluence with Mokelumne River
SWRCB Cottonwood Creek	Cottonwood Creek	Confluence with Sacramento River
SWRCB Cow Creek	Cow Creek	Confluence with Sacramento River
SWRCB Deer Creek	Deer Creek	Confluence with Sacramento River
SWRCB Delta	Sacramento River	Net Delta outflow
SWRCB Englebright	Yuba River	Below Englebright Dam
SWRCB Feather River	Feather River	Confluence
SWRCB Folsom	American River	Confluence
SWRCB Lake Berryessa	Putah Creek	Below Monticello Dam
SWRCB Mill Creek	Mill Creek	Confluence
SWRCB Mokelumne River	Mokelumne River	Upstream from confluence with Cosumnes River
SWRCB New Hogan	Calaveras River	Below New Hogan Dam
SWRCB Oroville	Feather River	Below Oroville Dam
SWRCB Putah Creek	Putah Creek	South Fork Putah Creek near Davis
SWRCB Sac ab Bend Bridge	Sacramento River	USGS Bend Bridge Gauge
SWRCB Sac at Butte City	Sacramento River	DWR Butte City Gauge
SWRCB Sac at Colusa	Sacramento River	Below Colusa Weir
SWRCB Sac at Freeport	Sacramento River	USGS Freeport gauge
SWRCB Sac at Hamilton	Sacramento River	DWR Hamilton Gauge
SWRCB Sac at Knights Landing	Sacramento River	Below Colusa Basin Drain outfall
SWRCB Sac at Ord Ferry	Sacramento River	DWR Ord Ferry Gauge
SWRCB Sac at Rio Vista	Sacramento River	Rio Vista Gauge
SWRCB Sac at Verona	Sacramento River	USGS Verona Gauge
SWRCB Sac at Vina	Sacramento River	DWR Vina Bridge Gauge
SWRCB Sac bw Wilkins Slough	Sacramento River	BUSGS Wilkins Slough Gauge
SWRCB Shasta	Sacramento River	Below Shasta Dam
SWRCB Stony Creek	Stony Creek	Confluence with Sacramento River
SWRCB Thomes Creek	Thomes Creek	Confluence with Sacramento River
SWRCB Trinity	Trinity River	Below Trinity Dam
SWRCB Yuba River	Yuba River	Confluence with Sacramento River

3.14 Streamflow Gauges

WEAP streamflow gauge objects allow rapid comparison of simulated flows to historical observed data using the WEAP results view. Gauge objects have also been included in SacWAM to help orientate the model user. They are represented by a blue circle with an associated diagonal arrow. SacWAM gauge names are prefixed with “HIS” to indicate associated data are historical observed mean monthly flows. The designation “FNF” indicates that full natural flow data[6] are available for the gauge.

Table 3-12 lists the gauges included in the model.

[6] For the purposes of this report “Full Natural Flow” indicates that observed gauge flows have been unimpaired for: (a) upstream storage regulation, (b) upstream reservoir evaporation, and (c) upstream imports and exports.

Table 3-12. Streamflow Gauges Represented in SacWAM

River/Channel	Gauge[1]	Gauge ID
Antelope Creek	HIS Antelope Ck nr Red Bluff	11379000
American River	HIS at Fair Oaks	11446500
Battle Creek	HIS Battle Ck nr Cottonwood	11376550
Bear River	HIS Bear bw Drum Afterbay	11421750_60_70
Bear River	HIS Bear bw Dutch Flat Afterbay	11421780_90
Bear River	HIS Bear bw Rollins Dam	11422500
Bear Creek	HIS Bear Ck nr Millville	11374100
Bear River	HIS Bear nr Wheatland	11424000
Bear River Canal	HIS Bear River Canal at Intake	11422000
Big Chico Creek	HIS Big Chico Ck nr Chico	11384000
Bowman Spaulding Conduit	HIS Bowman Spaulding Canal at Intake	11416000
Butte Creek	HIS Butte Ck nr Chico	11390000
Butte Creek	HIS Butte Ck nr Durham	11390010
Butte Slough	HIS Butte Slough nr Meridian	A02972
Butte Slough Outfall Gates	HIS Butte Slough Outfall Gates	A02967
Cache Creek	HIS Cache Ck ab Rumsey	11451760
Cache Creek	HIS Cache Ck at Yolo	11452500
Cache Creek	HIS Cache Ck nr Lower Lake	11451000
Camptonville Tunnel	HIS Camptonville Tunnel at Intake	11409350
Canyon Creek	HIS Canyon Ck bw Bowman	11416500
Clear Creek	HIS Clear Ck nr Igo	11372000
Colusa Basin Drain	HIS Colusa Basin Drain at Knights Landing	A02945
Colusa Basin Drain	HIS Colusa Basin Drain nr Highway 20	A02976
Colusa Weir	HIS Colusa Weir Spill to Butte Basin	A02981
Cosumnes River	HIS Cosumnes at Michigan Bar	11335000
Cottonwood Creek	HIS Cottonwood Ck nr Cottonwood	11376000
Cottonwood Creek	HIS Cottonwood Ck nr Olinda	11375810
Cow Creek	HIS Cow Ck nr Millville	11374000
Deer Creek Yuba	HIS Deer Ck nr Smartville	11418500
Deer Creek	HIS Deer Ck nr Vina	11383500
South Yuba Canal	HIS Deer Ck PH nr Washington	11414205
Drum Canal	HIS Drum Canal at Tunnel Outlet	11414170
Dry Creek Mok	HIS Dry Ck nr Ione	11328000
El Dorado Canal	HIS El Dorado Canal nr Kyburz	11439000
Elder Creek	HIS Elder Ck nr Paskenta	11379500
Feather River	HIS Feather at Oroville	11407000
Feather River	HIS Feather nr Nicolaus	11425000
Feather River	HIS Feather River nr Gridley	A05165
Fordyce Creek	HIS Fordyce Ck bw Fordyce Dam	11414100
Fremont Weir	HIS Freemont Weir Spill	A02930
French Meadows Hell Hole Tunnel	HIS French Meadows PH	11427200
Georgiana Slough	HIS Georgiana Slough	11447903
Gerle Creek	HIS Gerle Creek bw Loon Lake	11429500
Joint Board Canal	HIS Joint Board Canal	11406910
Jones Fork Tunnel	HIS Jones Fork PH	11440900
Clear Creek Tunnel	HIS Judge Francis Carr Powerhouse	11525430
Kelly Ridge Powerhouse	HIS Kelly Ridge PH nr Oroville	11396329
Lohman Ridge Tunnel	HIS Lohman Ridge Tunnel at Intake	11408870
Marsh Creek	HIS Marsh Ck nr Byron	11337500
McCloud River	HIS McCloud R above Shasta Lake	11368000
Middle Fork American River	HIS MF American at French Meadows	11427500
Middle Fork Feather River	HIS MF Feather nr Merrimac	11394500
Middle Fork Yuba River	HIS MF Yuba bw Milton Dam	11408550
Middle Fork Yuba River	HIS MF Yuba bw Our House Dam	11408880
Hell Hole Tunnel	HIS Middle Fork Powerplant	11428600
Mill Creek	HIS Mill Ck nr Los Molinos	11381500
Milton Bowman Tunnel	HIS Milton Bowman Tunnel at Outlet	11408000
Mokelumne River	HIS Mokelumne at Mokelumne Hill	11319500
Mokelumne River	HIS Mokelumne at Woodbridge	11325500
Mokelumne River	HIS Mokelumne River bw Camanche Dam	11323500

Table 3-12. Streamflow Gauges Represented in SacWAM contd.

River/Channel	Gauge[1]	Gauge ID
Moulton Weir	HIS Moulton Weir Spill A02986	A02986
South Canal	HIS Newcastle PP nr Newcastle	11425416
North Fork American River	HIS NF American at NF Dam	11427000
North Fork American River	HIS NF American nr Colfax	11426500
North Fork Feather River	HIS NF at Pulga	11404500
North Fork Cache Creek	HIS NF Cache Ck nr Clear Lake Oaks	11451300
North Fork Feather River	HIS NF Feather nr Prattville	1139950
Yuba River	HIS NF Yuba bw Goodyears Bar	11413000
Oregon Creek	HIS Oregon Ck bw Log Cabin Dam	11409400
Paynes Creek	HIS Paynes and Sevenmile Cks	11377500
Pit and Upper Sacramento River	HIS Pit R near Montgomery Ck	11365000
Pit and Upper Sacramento River	HIS Pit R nr Bieber	11352000
Putah Creek	HIS Putah Ck bw Diversion Dam	n/a
Putah Creek	HIS Putah Ck nr Winters	11454000
Putah South Canal	HIS Putah South Canal	11454210
Richvale Canal	HIS Richvale Canal	11406890
Robbs Peak Tunnel	HIS Robbs Peak PP	11429300
Rubicon River	HIS Rubicon bw Hell Hole Dam	11428800
Honcut Creek	HIS S Honcut Ck nr Bangor	11407500
Sacramento River	HIS Sacramento ab Bend Bridge	11377100
Sacramento River	HIS Sacramento at Butte City	11389000
Sacramento River	HIS Sacramento at Colusa	11389500
Sacramento River	HIS Sacramento at Freeport	11447650
Sacramento River	HIS Sacramento at Hamilton City	A02630
Sacramento River	HIS Sacramento at Keswick	11370500
Sacramento River	HIS Sacramento at Ord Ferry	A02570
Sacramento River	HIS Sacramento at Verona	11425500
Sacramento River	HIS Sacramento at Vina	A02700
Sacramento River	HIS Sacramento River above Delta	11342000
Sacramento River	HIS Sacramento River at Rio Vista	11455420
Sacramento River	HIS Sacramento River bw Wilkins Slough	11390500
Sutter Bypass	HIS Sacramento Slough nr Karnak	A02926
Sacramento Weir	HIS Sacramento Weir	11426000
San Joaquin River	HIS San Joaquin nr Vernalis	11303500
South Fork American River	HIS SF American nr Kyburz	11439500
South Fork American River	HIS SF American nr Placerville	11444500
South Fork Cottonwood Creek	HIS SF Cottonwood Ck nr Olinda	11375870
South Fork Feather River	HIS SF Feather bw Diversion Dam	11395200
South Fork Feather River	HIS SF Feather bw Forbestown	11396200
South Fork Feather River	HIS SF Feather bw Little Grass Valley	11395030
South Fork Silver Creek	HIS SF Silver Creek nr Ice House	11441500
South Fork Yuba River	HIS SF Yuba at Jones Bar	11417500
Slate Creek Tunnel	HIS Slate Ck Diversion Tunnel	11413250
Slate Creek	HIS Slate Creek bw Diversion Dam	11413300
South Fork Tunnel	HIS South Fork Tunnel nr Strawberry	11395150
South Yuba Canal	HIS South Yuba Canal nr Emigrant Gap	11414200
Spring Creek Conduit	HIS Spring Creek Powerhouse at Keswick	11371600
Power Canal	HIS Thermalito Afterbay Release	11406920
Power Canal	HIS Thermalito Power Plant	11406850
Thomes Creek	HIS Thomes Ck at Paskenta	11382000
Tisdale Weir	HIS Tisdale Weir Spill to Sutter Bypass	A02960
Toadtown Canal	HIS Toadtown Canal ab Butte Canal	11389800
Trinity River	HIS Trinity at Lewiston	11525500
Wise Canal	HIS Wise PH nr Auburn	11425415
Yolo Bypass	HIS Yolo Bypass nr Woodland	11453000
Yuba River	HIS Yuba bw Englebright nr Smartville	11418000
Yuba River	HIS Yuba River nr Marysville	11421000
Western Canal	HISWestern Canal and PGE Lateral	11406880

Note: SacWAM gauges are prefixed with 'HIS' to indicate associated data are historical observed mean monthly flows.

3.15 Data Directory

Table 3-13 provides file location information relating to the "SacWAM data and information" DVD for the datasets referenced in this chapter.

Table 3-13. File Location for SacWAM Schematic Construction

Referenced Name	File Name	File Location
American boundaries	AmRiv_blw_Ntms_Sheds_v20130730.shp	GIS\Boundaries
Bulletin 118 GW basins	B118_BasinBoundaries_v41.shp	GIS\Hydrology
canal miles	sac_val_canal_miles.shp	GIS\Hydrology
demand units	sac_val_demand_units.shp	GIS\Boundaries
flow accumulation	nhdplusfac18b, nhdplusfac18c	GIS\Hydrology
groundwater basin intersection	sac_val_groundwater_intersection.shp	GIS\Hydrology
groundwater basins	sac_val_groundwater_basins.shp	GIS\Hydrology
groundwater functions	GroundwaterFunctions.xlsm	Data\Supply_and_Resources\Groundwater\
gw basins spreadsheet	SACVAL_Groundwater.xlsx	Data\Supply_and_Resources\Groundwater\
HUC-12 watersheds	NRCS_HUC12s.shp	GIS\Hydrology
returns intersection	sac_val_returns_intersection.shp	GIS\Hydrology
river miles	sac_val_stream_miles.shp	GIS\Hydrology
surface returns	SACVAL_Surface_Runoff_and_Returns.xlsx	Data\Supply_and_Resources\Runoff_Infiltration_ and_Return_Flows
valley floor returns	sac_val_returns.shp	GIS\Hydrology
water budget areas	water_budget_areas.shp	GIS\Boundaries
watershed boundaries	sac_val_watersheds.shp	GIS\Hydrology

Chapter 4 Demand Sites and Catchments – Delta and Valley Floor

This chapter describes the representation of water demands and water use on the Sacramento Valley floor portion of SacWAM using WEAP's catchment objects. Catchments are divided by land use type into agricultural, urban, and refuge. Additionally, 'demand sites' are used to represent urban water demands and deliveries to water users located outside the model domain (e.g., SWP south-of-Delta contractors).

Description of catchment objects properties/parameters is organized using headings of the data tree in the WEAP software. Screenshots of the WEAP interface for each parameter are provided where possible to help the model user understand where parameters are entered in to the model.

4.1 Delineation of Valley Floor

4.1.1 Water Budget Areas

The valley watersheds are aggregated into 25 WBAs (Figure 4-1). SacWAM WBAs are aggregated versions of WBAs defined by DWR for use in their planning models. The one exception to this is WBA 61N, where SacWAM only represents the area to the north of the Stanislaus River.

WBAs describe large regions with similar characteristics (e.g., climatic conditions). In SacWAM, WBAs serve the following purposes:

- To define the boundary of non-district agricultural water users within a region who are aggregated and represented as a single water demand.
- To define the boundary of scattered water users whose water supplies for domestic (or industrial) use are self-produced, who rely on groundwater, and who are represented as a single water demand.
- To define the spatial resolution of hydrologic input data (e.g. precipitation, temperature, wind, and humidity).

In the 1960s, DWR subdivided the Central Valley into three hydrologic regions: Sacramento River, San Joaquin River, and Tulare Lake. These regions were in turn disaggregated into a total of 55 planning regions, termed Detailed Analysis Units (DAUs), which are DWR's standard unit for collecting and reporting land use data, preparing water budgets, and making projections for land use change and urban growth for the California Water Plan. Many of the WBAs follow the boundaries of DAUs, which represent the resolution of DWR's land use and water-use data. This simplifies the generation of model input data and model validation through comparison with annual water budgets prepared by DWR for use in the California Water Plan (DWR, 2009a).

Figure 4-1. Valley Floor Water Budget Area Boundaries

4.1.2 Demand Units

WBAs are subdivided into DUs based on physical, legal, and contract types. DUs are computational units represented by WEAP catchment or demand objects in SacWAM, and represent groups of water users who have similar land uses, climatic conditions, water delivery systems, and water use efficiencies. DUs are differentiated by land use and contract types. Land use types include agricultural, urban, and managed wetland classes. Contract user types include CVP settlement contractors, CVP water service contractors, water right holders in the FRSA who have signed settlement agreements with DWR as part of the SWP, and non-project water users. Grouping users by their water entitlements and water use characteristics facilitates simulation of surface water availability under different hydrologic conditions, and proposed regulatory and operational changes.

4.1.2.1 *Naming Convention*

The naming convention provides a unique identifier for each DU, based on land use type, WBA, and contract type (Table 4-1). These pieces of information are separated by underscores within the naming scheme. The first character in the DU name indicates the land use type ("A" for irrigated agriculture, "U" for urban, and "R" for refuge), followed by the WBA number(s) in which the DU exists, and then by a character indicating the contract type ("S" for settlement or exchange contract holders, "P" for CVP or SWP water service contract holders, and "N" for non-project users). For example, in the naming scheme of DU "A_02_NA," "A" indicates that the DU is an irrigated agricultural area, "02" indicates that it is part of WBA 02, and "NA" specifies that these agricultural water users are provided by non-project sources. The final letter in the name is a repeat of the first letter. The reason for the repetition is due to a naming convention restriction in the WEAP software.

Table 4-1. Demand Unit Naming Convention

Land Use	Settlement/Exchange Contract Holder	CVP/SWP Contract Holder	Non-Project Water Users
Irrigated Agriculture	A_(WBA#)_SA	A_(WBA#)_PA	A_(WBA#)_NA
Urban	U_(WBA#)_SU	U_(WBA#)_PU	U_(WBA#)_NU
Refuge	N/A	R_(WBA#)_PR	R_(WBA#)_NR

Key: CVP = Central Valley Project; SWP=State Water Project; WBA=Water Budget Area.

There are some cases where a further distinction must be made in the naming convention. An example is "A_14_15N_NA," in which there are two groups of users sharing land use, contract type, and climatic characteristics, except that the groups have different water sources and returns. To differentiate between the two groups, a number is placed at the end of the naming scheme, creating DUs "A_14_15_NA1" and "A_14_15_NA2."

The naming convention discussed above provides an explanation of DUs located in WBAs, but there is another naming convention for DUs not contained within a WBA. In the case where municipal areas outside of a WBA are supplied by a river within the Sacramento River Hydrologic Region, a four- to five-character acronym is used. For example, "U_NAPA," represents the cities of Napa, St. Helena, Calistoga, Yountville, and American Canyon, supplied by the North Bay Aqueduct.

4.1.2.2 *Represented Area*

The valley floor portion of the model represents a total of approximately 6,060,000 acres. Agricultural land makes up 5,474,000 acres (680,000 acres of which is agricultural land within the Delta), urban areas make up 538,000 acres, and refuge land accounts for 49,000 acres (Figure 4-2). These areas are represented by a total of 174 DUs, 74 of which are agricultural DUs, 58 of which are urban DUs, and six of which are refuge DUs.

Table 4-2, Table 4-3, and Table 4-4 list each SacWAM DU with water provider information. For agricultural DUs, the water district (WD) or WA supplying water to the DU is listed; for urban DUs the represented municipal area and water agency supplying this area is listed; and for refuge DUs, the associated refuge area and water provider is listed.

Agricultural Lands

SacWAM represents agricultural water use in the Sacramento Valley using DUs built on the standard WEAP catchment object. Each DU receives water from a network of arcs, (known as *Transmission Links* in WEAP), which can include multiple surface water and groundwater sources. All agricultural DUs have at least one groundwater source, and most have a surface source(s) also. The surface water supply arcs link to specified RMs or CMs on a surface water body. Runoff arcs—of which there can be several—from the DU to the stream network convey both rainfall runoff and irrigation return flows. Runoff arcs from the DU to underlying groundwater aquifer(s) represent deep percolation from precipitation and irrigation. At runtime, SacWAM dynamically simulates crop water demands, water deliveries, groundwater pumping, irrigation return flows, and rainfall runoff.

There are 74 agricultural catchment objects in SacWAM, defining the majority of land use on the valley floor (Figure 4-2). Table 4-2 contains a list of all SacWAM agricultural DUs, with the name of the WD or WA represented by the DU. The assignment of land to DUs not only takes into account WD boundaries and access to surface water, but also similarity of cropping patterns and water use efficiency.

Urban Lands

Urban water demands represent a small portion of total water demand when compared to agricultural use but their representation in SacWAM is still significant. In the past, urban demands have been met largely through groundwater pumping rather than through the supply of surface water. However, there is notable predicted urban growth during the next 20 years, which will require a reassessment of urban water demands, and perhaps greater reliance on surface sources (California Water Foundation, 2014).

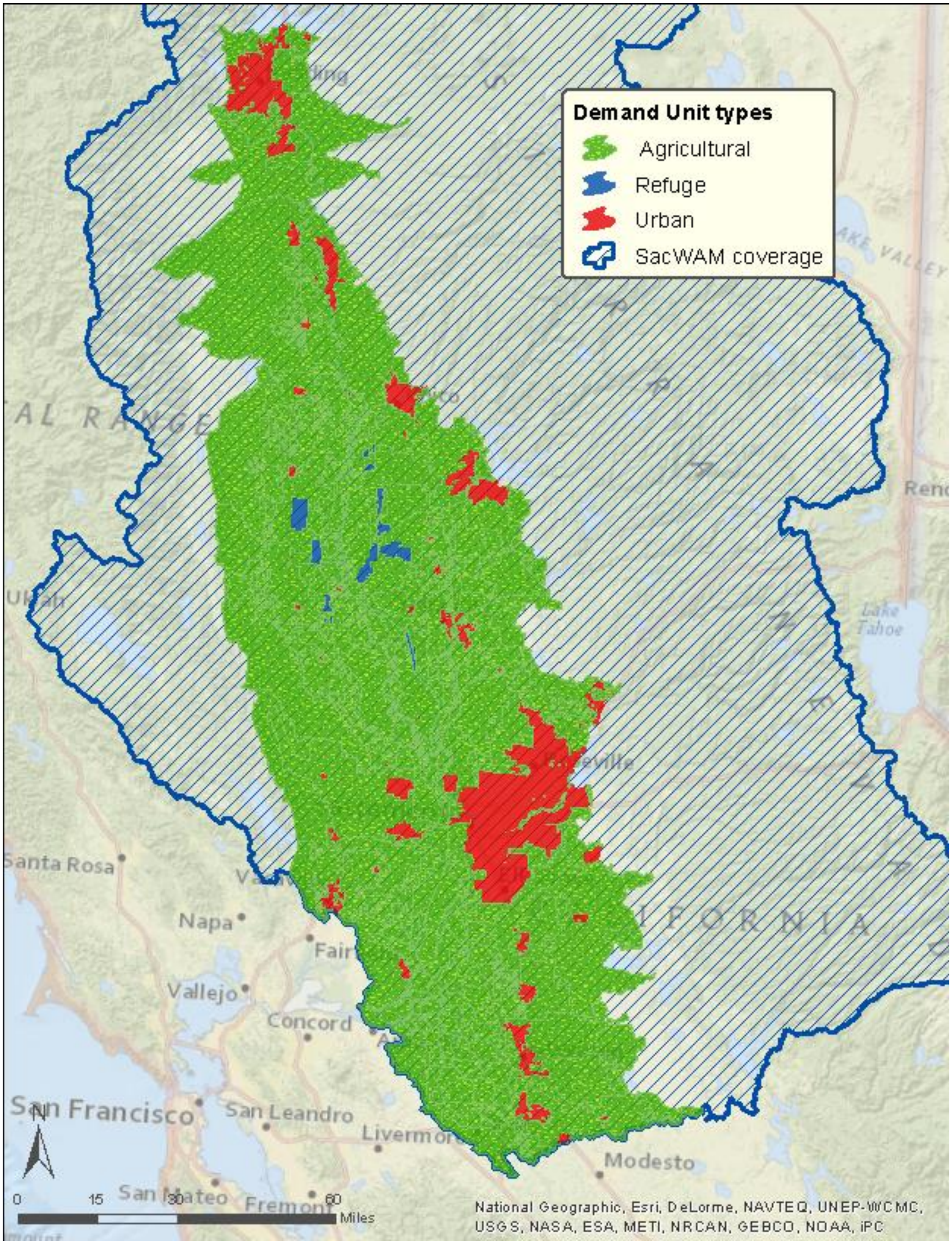


Figure 4-2. Agricultural, Refuge, and Urban Demand Units

There are 58 urban DUs that are identified in SacWAM (Figure 4-2). Forty-nine of these units are located in WBAs within the Sacramento Valley. Each WBA contains a minimum of one urban DU, but in some cases, there are multiple urban DUs within a WBA to account for differing sources of water, contract types, water rights, or water treatment technology. There are also nine urban DUs located in the upper watersheds. Although these DUs are outside of the valley floor, their representation in SacWAM is necessary, as these DUs are supplied by exports from canals and rivers that originate within the Sacramento Valley.

Typically in WEAP models, urban DUs are represented by a single demand site object. However, DUs that are in the Sacramento River Hydrologic Region are represented by both a catchment object and demand site object, placed next to one another. For example, DU “U_03_PU” will have demand site object “U_03_PU” and catchment object “U_03_PU_O.” The demand site object represents indoor and outdoor urban demands derived from purveyor data. The catchment object represents the rainfall runoff processes for the entire urban land area. The catchment node is differentiated from the demand site node with a “_O” suffix.

Similar to agricultural catchments, a single urban catchment, such as “U_03_PU_O,” will have one or multiple runoff links to the stream network and one or more infiltration links to a groundwater basin(s) representing deep percolation. The demand site, such as “U_03_PU” will have one or multiple transmission links from a surface source(s) and/or groundwater basin(s) (as some urban DUs conjunctively use surface water and groundwater), and a return flow link(s) to a surface water body(s).

Refuge Lands

In SacWAM, refuges are the third major land use classification. The SacWAM refuge classification includes National Wildlife Refuges (NWRs), National Wildlife Management Areas (WMA) and State Wildlife Areas (WA). According to the California Department of Fish and Wildlife (CDFW) (2014), refuges include areas that are “flooded and drained during specific periods of the year utilizing dikes, water control structures, pumps and/or other structures to enhance wildlife habitat values for specific species.” There are also private wetlands within agricultural catchments, but these were combined with crop water demands and included as part of the agricultural demand.

Refuge DUs are represented by six demand site objects in SacWAM (Figure 4-2). A single demand site will have one or multiple transmission links from a surface source(s) and a groundwater basin(s), and runoff link(s) to a surface water body in addition to infiltration to a groundwater basin(s).

Table 4-2. Agricultural Demand Units in Sacramento River Hydrologic Region

WBA	Demand Unit	Water District or Agency	Water Provider
02	A_02_NA	Non-district	N/A
	A_02_PA	Clear Creek CSD	CVP
	A_02_SA	Anderson-Cottonwood ID Misc. settlement contractors	CVP
03	A_03_NA	Non-district	N/A
	A_03_PA	Bella Vista WD	CVP
	A_03_SA	Anderson-Cottonwood ID Misc. settlement contractors	CVP
04_06	A_04_06_NA	Non-district (including misc. settlement contractors)	N/A
	A_04_06_PA1	Corning WD Proberta WD Thomes Creek WD	CVP
	A_04_06_PA2	Kirkwood WD	CVP
	A_04_06_PA3	Orland Unit WUA	Reclamation
05	A_05_NA	Los Molinos MWC Non-district (including misc. CVP settlement contractors)	N/A
07	A_07_NA	Non-district	N/A
	A_07_PA	Glide WD Holthouse WD Kanawha WD Orland-Artois WD 4-M WD Colusa County WD Cortina WD Davis WD Dunnigan WD Glenn Valley WD La Grande WD Myers-Marsh MWC Westside WD	CVP
08	A_08_NA	Non-district	N/A
	A_08_PA	Colusa Drain MWC	CVP
	A_08_SA1	Maxwell ID Princeton-Codora-Glenn ID Provident ID Sycamore Family Trust Misc. settlement contractors	CVP
	A_08_SA2	Glenn-Colusa ID	Glenn-Colusa ID (55% of total)
	A_08_SA3	RD 108 River Garden Farms Misc. settlement contractors	CVP
09	A_09_NA	Llano Seco Ranch Dayton MWC Non-district	N/A
	A_09_SA1	Pacific Realty Associates (formerly M&T Chico Ranch)	CVP
	A_09_SA2	RD 1004 Carter MWC Jack Baber Misc. settlement contractors	CVP
10	A_10_NA	Rancho Esquon Durham MWC Non-district	N/A

Table 4-2. Agricultural Demand Units in Sacramento River Hydrologic Region cont.

WBA	Demand Unit	Water District or Agency	Water Provider
11	A_11_NA	Sutter Butte MWC Non-district	N/A
	A_11_SA1	Western Canal WD	SWP
	A_11_SA2	Richvale ID	SWP
	A_11_SA3	Biggs-West Gridley WD Butte WD	SWP
	A_11_SA4	Sutter Extension WD	SWP
12_13	A_12_13_NA	South Feather Water and Power Agency Yuba County WD Non-district	N/A
	A_12_13_SA	Misc. FRSA diverters	N/A
14_15N	A_14_15N_NA1	Non-district	N/A
	A_14_15N_NA2	Cordua ID Hallwood ID Ramirez WD	Yuba County WA
	A_14_15N_NA3	Browns Valley ID	Browns Valley ID, Yuba County WA
	A_14_15N_SA	Misc. FRSA diverters	N/A
15S	A_15S_NA	Non-district Wheatland WD Dry Creek WD South Yuba WD Brophy WD	N/A Yuba County WA
	A_15S_SA	Plumas MWC Misc. FRSA diverters	SWP
16	A_16_NA	Non-district	N/A
	A_16_PA	Feather WD	CVP
	A_16_SA	Garden Highway MWC Tudor ID Oswald ID Misc. FRSA diverters	SWP
17	A_17_NA	Sutter Bypass-Butte Slough WUA Non-district	N/A
	A_17_SA	Misc. FRSA diverters Minor settlement contractors	N/A
18_19	A_18_19_NA	Butte Slough Irrigation Company Sutter Butte MWC Non-district	N/A
	A_18_19_SA	Meridian Farms WC Lomo Cold Storage Sutter MWC Tisdale IDC Bardis et al. Pelger MWC Misc. settlement contractors	CVP
20_25	A_20_25_NA1	Yolo County Flood Control & WCD Non-district	N/A
	A_20_25_NA2	North Delta WA Non-district	N/A
	A_20_25_PA	University of California at Davis Solano ID Maine Prairie WD	Solano County WA Reclamation Reclamation
21	A_21_NA	Non-district	N/A
	A_21_PA	Colusa Drain MWC (22% of total)	CVP
	A_21_SA	Conaway Conservancy Group Misc. settlement contractors	N/A

Table 4-2. Agricultural Demand Units in Sacramento River Hydrologic Region cont.

WBA	Demand Unit	Water District or Agency	Water Provider
22	A_22_NA	Non-district	N/A
	A_22_SA1	Natomas Central MWC Pleasant Grove-Verona MWC Misc. settlement contractors	CVP
	A_22_SA2	Misc. FRSA diverters	N/A
23	A_23_NA	Camp Far West ID South Sutter ID Non-district	South Sutter WD
24	A_24_NA1	Nevada ID	Nevada ID
	A_24_NA2	Placer County WA Zone 5 Non-district	Placer County WA
	A_24_NA3	Placer County WA Zone 1	Placer County WA
26	A_26_NA	Non-district	N/A
50	A_50_NA1	North Delta WA	N/A
	A_50_NA2	North Delta WA	N/A
	A_50_NA3	Central Delta WA North Delta WA	N/A
	A_50_NA4	Central Delta WA North Delta WA	N/A
	A_50_NA5	Central Delta WA North Delta WA South Delta WA	N/A
	A_50_NA6	Byron Bethany ID Central Delta WA North Delta WA	N/A
	A_50_NA7	Byron Bethany ID South Delta WA	N/A
60N	A_60N_NA1	Jackson Valley ID	N/A
	A_60N_NA2	Omochumne-Hartnell WD Clay WD Galt ID	N/A
	A_60N_NA3	North San Joaquin WCD	N/A
	A_60N_NA4	Woodbridge ID Woodbridge Users Association	N/A
	A_60N_NA5	Non-district Riparian diverters	N/A
60S	A_60S_NA	Non-district east Non-district west	N/A
	A_60S_PA	Stockton East WD Central San Joaquin WCD	CVP Reclamation CVP
61N	A_61N_PA	Oakdale ID north South San Joaquin ID	CVP
	A_61N_NA1	Non-district east	N/A
	A_61N_NA2	Non-district Stanislaus River riparian diverters	N/A
	A_61N_NA3	Non-district San Joaquin River riparian diverters downstream from Stanislaus River confluence	N/A

Key: CSD=Community Service District; CVP=Central Valley Project; DWR=Department of Water Resources; FRSA=Feather River Service Area; ID=Irrigation District; IDC=Irrigation and Drainage Company; Misc.=miscellaneous; MWC=Mutual Water Company; N/A=not applicable; Reclamation=U.S. Department of the Interior, Bureau of Reclamation; SWP=State Water Project; WA=Water Agency; WBA=Water Budget Area; WC=Water Company; WCD=Water Conservation District; WD=Water District; WUA=Water Users Association.

Table 4-3. Urban Demand Units in Sacramento River Hydrologic Region

WBA	Demand Unit	Cities, Towns, and Communities	Water Agency Retail (Wholesale)
02	U_02_NU	Anderson Cottonwood Lake California Small communities	City of Anderson Cottonwood WD Rio Alto WD Self-supplied
	U_02_PU	Centerville and Redding Happy Valley Shasta CSA No. 25 Shasta	Centerville CSD Clear Creek CSD Keswick CSA Shasta CSD
	U_02_SU	Redding- Foothill, Hill 900 and Cascade zones	City of Redding
03	U_03_NU	Small communities	Self-supplied
	U_03_PU	Shasta CSA No. 6 Shasta Lake Mountain Gate	Jones Valley CSA City of Shasta Lake Mountain Gate CSD
		Stillwater Valley Bella Vista Palo Cedro Redding	Bella Vista WD
		Redding- Buckeye and Hilltop zones	City of Redding
	U_03_SU	Redding- Hilltop and Enterprise zones	City of Redding
04_06	U_04_06_NU	Red Bluff Corning Gerber Orland Small communities	City of Red Bluff City of Corning Gerber-Las Flores CSD City of Orland Self-supplied
05	U_05_NU	Red Bluff Los Molinos Small communities	City of Red Bluff Los Molinos CSD Self-supplied
07	U_07_NU	Willows Arbuckle Small communities	California Water Service Company Arbuckle Public Utility District Self-supplied
08	U_08_NU	Hamilton City Colusa Williams Small communities	California Water Service Company City of Colusa City of Williams Self-supplied
09	U_09_NU	Small communities	Self-supplied
10	U_10_NU1	Chico	California Water Service Company
	U_10_NU2	Durham Small communities	Durham ID Self-supplied
11	U_11_NU1	Oroville	Thermalito ID
	U_11_NU2	Biggs Gridley Live Oak Small communities	City of Biggs City of Gridley Live Oak WD Self-supplied
12_13	U_12_13_NU1	Oroville	California Water Service Company; South Feather Water and Power Agency
	U_12_13_NU2	Small communities	Self-supplied ; South Feather Water and Power Agency
14_15N	U_14_15N_NU	Marysville Small communities	California Water Service Company Self-supplied
15S	U_15S_NU	Olivehurst Wheatland Linda Small communities	Olivehurst Public Utility District City of Wheatland Linda County WD Self-supplied
16	U_16_NU	Small communities	Self-supplied
	U_16_PU	Yuba City	City of Yuba City

Table 4-3. Urban Demand Units in Sacramento River Hydrologic Region cont.

WBA	Demand Unit	Cities, Towns, and Communities	Water Agency Retail (Wholesale)
17	U_17_NU	Sutter	Sutter CSD
		Small communities	Self-supplied
18_19	U_18_19_NU	Small communities	Self-supplied
20_25	U_20_25_NU	Davis El Macero Willowbank	City of Davis
		UC Davis	University of California at Davis
		Woodland	City of Woodland
		Winters	City of Winters
		Esparto	Esparto CSD
		Madison	Madison CSD
		Rio Vista	City of Rio Vista
		Dixon	California Water Service Company
		Small communities	Self-supplied
	U_20_25_PU	Vacaville	City of Vacaville
21	U_21_NU	Knights Landing	Knights Landing Service District
		Small communities	Self-supplied
	U_21_PU	West Sacramento (partly in Delta)	City of West Sacramento
22	U_22_NU	Sacramento International Airport	City of Sacramento
		Metro Air Park Northgate 880	Sacramento County WA- Zone 41
		Small communities	Self-supplied
23	U_23_NU	Small communities	Self-supplied
24	U_24_NU1	Auburn Bowman	Placer County WA- Upper Zone 1
		Christian Valley Park	Christian Valley Park CSD
		North Auburn	Nevada ID
		Small communities	Self-supplied
	U_24_NU2	Loomis Newcastle Penryn Rocklin Granite Bay (portion) City of Roseville (portion)	Placer County WA- Lower Zone 1
		City of Lincoln	Placer County WA
		West Placer	Cal-Am WC; Placer County WA
26	U_26_NU1	Northridge	Sacramento Suburban WD-North SA; McClellan; San Juan WD
		Arbors at Antelope McClellan Business Park	Sacramento Suburban WD-North SA; McClellan; San Juan WD
		Arcade- North Highlands	Sacramento Suburban WD-North SA; McClellan; San Juan WD
		Antelope	Cal-Am WC; San Juan WD
		Lincoln Oaks	Cal-Am WC; San Juan WD
		Rio Linda	Rio Linda Elverta CWD; San Juan WD
		Elverta	Rio Linda Elverta CWD; San Juan WD
		Arcade	Sacramento Suburban WD- South SA; City of Sacramento
		Arden	Golden State WD
		Del Paso Service Area	Del Paso Manor WD
		Arden Park Vista Service Area	Sacramento County WA- Zone 41
		Arden	Cal-Am WC
	U_26_NU2	Carmichael	Carmichael WD
	U_26_NU3	City of Sacramento- North City of Sacramento- South	City of Sacramento

Table 4-3. Urban Demand Units in Sacramento River Hydrologic Region cont.

WBA	Demand Unit	Cities, Towns, and Communities	Water Agency Retail (Wholesale)
26	U_26_NU4	Parkway	Cal-Am WC; City of Sacramento
		Suburban	Cal-Am WC; City of Sacramento
		Rosemont	Cal-Am WC; City of Sacramento
		Florin Fruitridge Tokay Park	Florin County WD Fruitridge Vista WD Tokay Park WC- Zone 41
	U_26_NU5	Groundwater remediation	Aerojet
	U_26_NU6	Folsom Lake shoreline	California Parks and Recreation
	U_26_PU1	Roseville	City of Roseville
	U_26_PU2	San Juan Retail Service Area Orange Vale City of Citrus Heights Fair Oaks City of Folsom Ashland	San Juan WD Orange Vale WC Citrus Heights WD Fair Oaks WD City of Folsom San Juan WD
	U_26_PU3	City of Folsom Folsom State Prison	City of Folsom Folsom State Prison
	U_26_PU4	Laguna City of Elk Grove Vineyard Mather-Sunrise Sunrise/Security Park	Sacramento County WA- South SA, Zone 40 Elk Grove WD- Tariff Areas No. 1 and 2 Sacramento County WA- Central SA, Zone 40 Sacramento County WA- North SA, Zone 40 Cal-Am WC, Sacramento County WA
	U_26_PU5	Rancho Cordova	Golden State WC
60N	U_60N_NU1	Galt (City of Galt) Lodi (City of Lodi) Small communities	City of Galt City of Lodi Self-supplied
	U_60N_NU2	Rancho Murieta	Rancho Murieta CSD
	U_60N_PU	Rancho Seco Power Plant	Sacramento Municipal Utility District
60S	U_60S_NU1	City of Stockton	City of Stockton; California Water Service Company
	U_60S_NU2	Small communities	Self-supplied
61N	U_61N_NU1	Lathrop	City of Lathrop South San Joaquin ID
		Escalon	City of Escalon South San Joaquin ID
		Manteca	South San Joaquin ID
	U_61N_NU2	Ripon Oakdale Riverbank Small communities	City of Ripon City of Oakdale City of Riverbank Self-supplied
Supplied by rivers or exports from Valley Floor but not located within a WBA	U_ANTOC	Antioch	City of Antioch
	U_CCWD	Bay Point Clayton Clyde Oakley Pittsburg Port Costa	Contra Costa Water District
	U_CLLPT	Clear Lake Lakeport Small communities	M&I water purveyors
	U_EBMUD	Berkeley Oakland Richmond Walnut Creek	East Bay Municipal Utility District
	U_ELDID	El Dorado Hills	El Dorado Hills ID

Table 4-3. Urban Demand Units in Sacramento River Hydrologic Region cont.

WBA	Demand Unit	Cities, Towns, and Communities	Water Agency Retail (Wholesale)
Supplied by rivers or exports from Valley Floor but not located within a WBA	U_FVTB	Fairfield	City of Fairfield
		Vallejo	City of Vallejo
		Travis Air Force Base	Travis Air Force Base
		Benicia	City of Benicia
		California State Prison- Solano	California State Prison Solano
		Suisun	City of Suisun
	U_JLIND	Jenny Lind/Valley Springs	Calaveras County WD
	U_NAPA	American Canyon	City of American Canyon
		Napa City of St. Helena	City of Napa
		Calistoga	City of Calistoga/Napa
	U_PCWA3	Alta	Dutch Flat Mutual WC
		Dutch Flat	Weimar WC
		Colfax	Midway Heights County WD
		Applegate	Heather Glen CSD
		Meadow Vista	Meadow Vista County WD

Key: CSA=Community Service Area; CSD=Community Service District; CWD=Community Water District; ID=Irrigation District; N/A=not applicable; SA=Service Area; WA=Water Agency; WBA=Water Budget Area; WC=Water Company; WD=Water District; WSD=Water Service District.

Table 4-4. Refuge Demand Units in Sacramento River Hydrologic Region

Water Budget Area	Demand Unit	Refuge/Wildlife Area	Water Provider
08	R_08_PR	Sacramento NWR Delevan NWR Colusa NWR	Reclamation
09	R_09_PR	Llano Seco Unit, Upper Butte Basin SWA Llano Seco Unit, Sacramento River NWR	Water rights
11	R_11_PR	Little Dry Creek, Upper Butte Basin SWA Howard Slough Unit, Upper Butte Basin SWA	Western Canal WD Richvale ID
17	R_17_NR	Butte Sink Duck Clubs	Water rights
			Western Canal WD
	R_17_PR1	Gray Lodge SWA	Reclamation
			DWR (by Exchange)
	R_17_PR2	Sutter NWR	Reclamation
			Sutter Extension WD

Key: DWR=Department of Water Resources; ID=Irrigation District; NWR=National Wildlife Refuge; SWA=State Wildlife Area; WD=Water District.

4.2 Simulation of Crop Water Demands

On the valley floor, evapotranspiration from the land surface is calculated on a daily time step using the dual crop coefficient approach described in Food and Agricultural Organization (FAO) Irrigation and Drainage Paper No. 56 (Allen et al., 1998). Within the WEAP software this approach is referred to as the MABIA method. The method requires inputs of temperature, precipitation, humidity, and windspeed. These data are used to calculate a reference evapotranspiration using the Penman-Monteith Equation. Individual crop types are assigned crop coefficients which are used to scale the reference evapotranspiration to reflect crop specific planting dates, canopy development rates, and harvest dates. In SacWAM, this approach is also used to simulate bare soil evaporation and water use by native and wetland vegetation.

In addition to calculating plant and soil evapotranspiration, the MABIA method calculates surface runoff, infiltration, and deep percolation. For this reason, in addition to the climatic inputs mentioned above, the MABIA algorithm requires specification of soil parameters such as soil water capacity and soil depth. The Soil Conservation Service (SCS) curve number method is used in a modification to the MABIA method to calculate effective rainfall. This modification is described in Section 4.4.3.4. For more details on the MABIA method, the reader is referred to the Help files of the WEAP software (Help>Contents>Calculation Algorithms>Evapotranspiration, Runoff, Infiltration, and Irrigation>MABIA Method).

Crop water use parameters for the MABIA module were based on information obtained from the Sacramento – San Joaquin Basin Study. Planting dates, season length, and single crop coefficient values were obtained from the study (Table 4-5, Table 4-6, and Table 4-7). A discussion of the calibration of the crop coeffiencts is provided in Appendix B.

Table 4-5. Perennial Crop Season Length and Date Parameters Used in CUP Model for Basin Study

Crop	Length of Growing Season (Days)	Start of Growing Season	End of Growing Season
Alfalfa (annual)	365	1-Jan	31-Dec
Almonds	229	1-Mar	15-Oct
Apple	229	1-Apr	15-Nov
Orange	365	1-Jan	31-Dec
Pasture (improved)	365	1-Jan	31-Dec
Wine grapes	215	1-Apr	1-Nov

Table 4-6. Annual Crop Season Length and Date Parameters Used in CUP Model for Basin Study

Crop	Length of Growing Season (Days)	Planting Date	Harvest Date
Beans (dry)	108	15-Jun	30-Sep
Corn (grain)	153	1-May	30-Sep
Corn (silage)	107	1-May	15-Aug
Cotton	154	15-May	15-Oct
Cucumber	93	15-May	31-Aug
Melon	123	15-May	15-Sep
Onion (dry)	215	1-Mar	1-Oct
Potato	123	15-Apr	15-Aug
Rice	139	15-May	30-Sep
Safflower	122	1-Apr	31-Jul
Sugarbeet	200	15-Mar	30-Sep
Tomato	153	1-Apr	31-Aug
Wheat	212	1-Nov	31-May

Table 4-7. Season Length and Crop Coefficient Parameters Used in CUP Model for Basin Study

Crop	Length of Season (Days)	Percent of Growing Season			Crop Coefficients		
		Initial	Development	Mid-Season	K_c ini	K_c mid	K_c end
Alfalfa (annual)	365	25	50	75	1.00	1.00	1.00
Almonds[1]	229	0	50	90	0.55	1.20	0.65
Apple	229	0	50	75	0.55	1.15	0.80
Beans (dry)	108	24	40	91	0.20	1.10	0.10
Corn (grain)	153	20	45	75	0.20	1.05	0.60
Corn (silage)	107	20	45	100	0.20	1.05	1.00
Cotton	154	15	25	85	0.35	1.00	0.50
Cucumber	93	19	47	85	0.80	1.00	0.75
Melon[2]	123	21	50	83	0.75	1.05	0.75
Onion (dry)	215	13	42	72	0.55	1.20	0.55
Orange[1]	365	0	33	67	1.00	1.00	1.00
Pasture (improved)	365	25	50	75	0.95	0.95	0.95
Potato	123	20	45	78	0.70	1.15	0.50
Rice[3]	139	24	37	86	1.16	1.04	1.05
Safflower	122	17	45	80	0.20	1.05	0.25
Sugarbeet	200	15	45	80	0.20	1.15	0.95
Tomato	153	25	50	80	0.20	1.20	0.60
Wheat	212	25	60	90	0.30	1.05	0.15
Wine grapes	215	0	25	75	0.45	0.80	0.35

Notes:
1. Mid-season crop coefficients for almonds and other tree crops may vary between 0.90 – 1.15 depending on whether a cover crop is present.
2. The growing season for melons was revised from 229 days given in CUP to 123 days.
3. Rice parameters were updated for this study using crop coefficients from Linquist et al. (2015).

4.3 Climate

Historical climate data were needed for the entire model domain for the period 1921 to 2009. In consultation with SWRCB staff, the SacWAM development team selected a spatially interpolated, gridded dataset developed by Livneh et al. (2013) as the source for historical climate data. This dataset provides daily precipitation, maximum and minimum temperature, and wind speed (at 10m) for January 1, 1915 to December 31, 2011 on a 1/16 degree grid. The following steps were followed in developing the data:

1. The **Livneh grid** was intersected with the **water budget areas** boundaries.
2. A VBA macro in **valley floor processor** was used to calculate the average of the maximum and minimum daily temperature, precipitation, and wind speed for all **Livneh grid** cells that intersected each WBA.
3. The spreadsheet **Daily CIMIS RH Analysis** was used to calculate an average maximum and minimum daily relative humidity timeseries based on CIMIS data.
4. Data from steps 2 and 3 were combined to create the input files found in **WEAP Input Data**.

The wind data in the Livneh et al. (2013) dataset is provided as wind speed at 10 m above the ground. This data was modified to represent wind speed at 2 m above the ground using the following relationship (Neitsch et al., 2005):

$$wind_2 = wind_{10} * (2/10)^{0.2} \qquad \text{Equation 4-1}$$

where:

$wind_2$ is the wind speed at 2 m above the ground;

$wind_{10}$ is the wind speed at 10 m above the ground.

4.4 Agricultural Catchment Parameters

SacWAM represents agricultural water use in the Sacramento Valley using demand units built on the standard WEAP catchment object. Within each catchment, calculations of crop ET are performed for each crop type using the MABIA method described above. To meet the crop water demand, the demand unit receives water from surface water and groundwater sources via transmission links (solid green line). Return flows are routed using the dashed blue line which represents either runoff (for surface water) or infiltration (for deep percolation). These links convey return flows from both rainfall and irrigation. Agricultural catchments can be recognized by their "A_" prefix.

4.4.1 Conceptual Framework

Agricultural water use in the SacWAM is represented using the conceptual framework illustrated in Figure 4-3. The solid lines shown in the figure are represented in the SacWAM schematic. Additional dashed lines are used to describe water use within the demand unit and are conceptual in nature. Definitions of each flow arc are provided in Table 4-8.

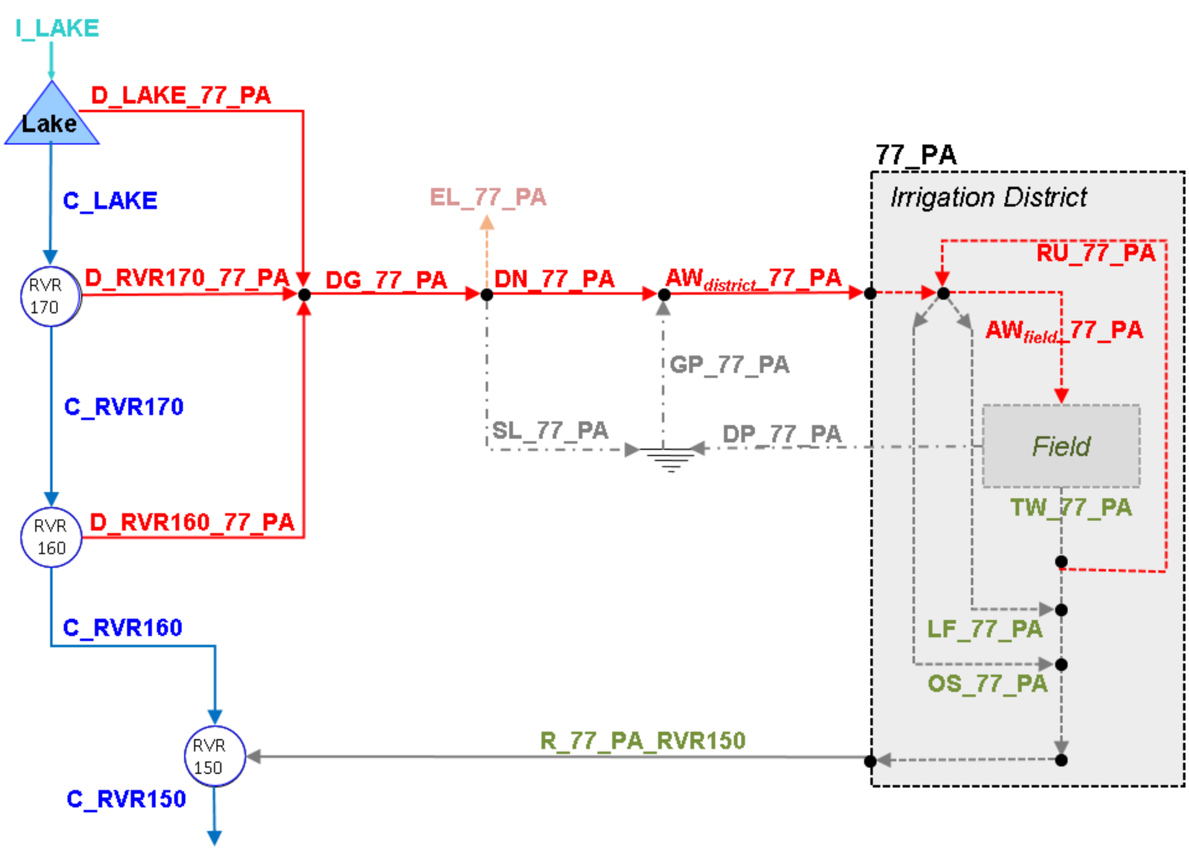


Figure 4-3. Template for Agricultural Water Use

Table 4-8. Flow Arcs for Agricultural Water Use

Arc Prefix	Name	Description
DG	Diversion Gross	The sum of all surface water diversions from the stream or canal system to the demand unit.
DN	Diversion Net	Net surface water reaching the district after accounting for evaporation and seepage conveyance losses.
EL	Evaporation Loss	Evaporative loss from surface water conveyance channels, including that from riparian growth adjacent to these channels.
SL	Seepage Loss	Seepage loss from conveyance structures such as canals.
LF	Lateral Flow Loss	Lateral flow through the banks of the canal distribution system to the adjacent toe drains.
OS	Operational Spill Loss	Flow leaving the canal distribution system, discharging directly to the drain system.
GP	Groundwater Pumping	Groundwater pumping (not subject to conveyance losses).
RU	Reuse	Reuse of tailwater, operating spills, and lateral flows at farm and district scales.
AW_{field}	Applied Water	Applied water at field scale, after accounting for losses from lateral flow and operational spills and supplies from reuse of water.
$AW_{district}$	Applied Water	Applied water at district scale is the sum of surface water deliveries, less conveyance loss, and groundwater pumping.
DP	Deep Percolation Loss	Deep percolation of irrigation water and precipitation at field scale.
TW	Tailwater	Return flow from irrigation at field scale.
R	Return Flow	Return flow at district scale consisting of operational spills, lateral flow, and tailwater, which are not reused.

In the conceptual framework, water supplies available to meet crop water demands are a mix of stream and canal diversions, groundwater pumping, and reuse of tailwater. Stream diversions and deliveries from major canal systems are subject to conveyance losses (evaporation and seepage). In contrast, groundwater pumping is considered to be at field level and not subject to conveyance losses, unless a water district supplements canal deliveries with groundwater pumping into the district canal distribution system. The canal distribution system within an ID is subject to operational spills and lateral flow through the canal banks to adjacent toe drains. Tailwater leaving the field (including flow-through from rice fields and drawdown of ponded water) is available for reuse. Water supplies must meet applied water demands. A fixed fraction of water demands must be met from groundwater pumping, representing farmers who do not have access to surface water.

Groundwater pumping is assumed to be at field scale. Therefore, simulated groundwater pumping is not subject to operational spills and lateral flows. However, in the case of surface water, these flows cannot be represented explicitly in WEAP, and must be represented implicitly by reducing the irrigation efficiency.

4.4.1.1 *Applied Water*

The irrigation water required at the head of the field or farm gate is known as the applied water. The portion of irrigation water that is stored in the root zone and subsequently consumed through ET is known as the consumptive use of applied water. Applied water is related to the consumptive use of applied water by the seasonal application efficiency (SAE).

$$AW_{field}=CUAW/\ SAE \qquad \text{Equation 4-2}$$

where:

AW_{field}=applied water at head of the field
CUAW=consumptive use of applied water
SAE=seasonal application efficiency

Crop-specific SAEs are defined for each WBA. The term SAE is used, rather than irrigation efficiency, to indicate that values are constant over the irrigation season.

4.4.1.2 *Potential Application Efficiency*

Distribution uniformity is a measure of how uniformly water is distributed across the field. It is typically defined as the ratio of some measure of the smallest accumulated depths in the distribution of applied water to the average depth accumulated. Since 1940, NRCS has used the average of the lowest quarter of the distribution to the average of the distribution to define distribution uniformity (Burt et al., 1997). Distribution uniformity differs from irrigation efficiency. For example, water could be applied uniformly across the field, but in excess of crop water requirements and available soil moisture storage, resulting in a low application efficiency and deep percolation of applied water to groundwater. However, distribution uniformity can be used as an upper bound for potential application efficiency (PAE). PAE is based on the concept that the applied water is sufficient to achieve average soil moisture across the least watered quarter of the field equal to field capacity. For this assumption, PAE may be calculated using the following equation:

$$PAE_{field}=DU_{lq} \qquad \text{Equation 4-3}$$

where:

DU_{lq}=distribution uniformity based on the 'lower quarter' concept
PAE=potential application efficiency

SAEs estimated by DWR's Division of Statewide Integrated Water Management (DSIWM) are typically 1 to 1.10 times lower than PAEs based on DUs. The reason for this is that SAEs account for surface water leaving the field as tailwater. To account for this, the SAE is calculated as follows:

$$SAE_{field}=PAE.(1-f_{TW}) \qquad \text{Equation 4-4}$$

and:

$$AW_{field}=\frac{CUAW}{PAE.(1-f_{TW})} \qquad \text{Equation 4-5}$$

where:

f_{TW}=tailwater factor

As described above, at a district scale there are operational spills from the canal distribution system, and lateral flow through the canal banks to the toe drains. Tailwater leaving the field may be captured and reapplied. It is assumed that there is no reuse of operational spills and lateral flows.[7] The applied water at the boundary of the district and the associated SAE at the district scale may be calculated as follows:

$$AW_{district}=AW_{field}.\frac{(1-f_{RU})}{(1-f_{os}-f_{LF})} \qquad \text{Equation 4-6}$$

$$AW_{district}=\frac{CUAW}{PAE.(1-f_{TW})}.\frac{(1-f_{RU})}{(1-f_{os}-f_{LF})} \qquad \text{Equation 4-7}$$

$$SAE_{district}=PAE.\frac{(1-f_{TW}).(1-f_{OS}-f_{LF})}{(1-f_{RU})} \qquad \text{Equation 4-8}$$

where:

$SAE_{district}$=Seasonal application efficiency at district scale
f_{OS}=operational spill factor
f_{LF}=lateral flow factor
f_{TW}=tailwater factor
f_{RU}=reuse factor

Ideally, the operational spills and the lateral flows would be a function of the surface water deliveries rather than the applied water. However, currently there is no mechanism in the WEAP software to explicitly account for these flows. Therefore, operational spills and lateral flows have been included in the irrigation efficiency.

4.4.1.3 *Surface Water Demands*

The demand for surface water at field level is calculated as follows:

$$DN_{max}=(1-f_{GW}).AW_{district} \qquad \text{Equation 4-9}$$

where:

DN_{max}=demand for surface water
f_{GW}=minimum groundwater pumping factor

Surface water deliveries are subject to conveyance losses. When water supplies, water contracts, and/or water rights are not limiting, stream diversions (DG) or deliveries from major canal systems are determined as follows:

[7] Operational spills and lateral flows that are captured and used to meet applied water demands are nor represented in SacWAM as these flows are internal to the demand unit and do not affect the water balance.

$$DG_{max}=DN_{max}/(1 - f_{EV} - f_{SP}) \qquad \text{Equation 4-10}$$

where:

DG=gross surface water diversion (i.e., as measured at point of diversion)
f_{EV}=evaporative loss factor
f_{SP}=seepage loss factor

The net delivery (DN) is only equal to the demand for surface water (DN_{max}) when there are no binding constraints on surface water diversions.

4.4.1.4 *Surface Irrigation Return Flows*

Irrigation water returning to the stream system can be expressed as a function of the applied water demand at the district boundary, as follows:

$$RF=(f_{OS} + f_{LF}).AW_{district} + f_{TW}.AW_{field}.(1 - f_{RU}) \qquad \text{Equation 4-11}$$

$$RF=(f_{OS} + f_{LF}).AW_{district} + f_{TW}.AW_{district}.(1 - f_{OS} - f_{LF}) \qquad \text{Equation 4-12}$$

4.4.1.5 *Deep Percolation from Applied Water*

Irrigation water that infiltrates the soil surface and percolates to the underlying groundwater can be expressed as a function of the applied water demand at the district boundary, as follows:

$$DP=(1 - PAE) \qquad \text{Equation 4-13}$$

$$DP=AW_{field}.(1 - PAE - f_{TW}) \qquad \text{Equation 4-14}$$

$$DP=AW_{district}.\frac{(1-f_{OS}-f_{LF})}{(1-f_{RU})}.(1 - PAE - f_{TW}) \qquad \text{Equation 4-15}$$

4.4.1.6 *Ponded Fields (Rice and Flooded Refuge Lands)*

Fields that are ponded utilize a different conceptual model than the one described above. In SacWAM this applies to rice fields and the portions of refuges that are seasonally or permanently flooded.

Similar to other crops, there are seepage and evaporative losses from the canal system that are represented in the *Loss to Groundwater* and *Loss to System* on the transmission links that connect the DUs catchment object to a stream.

Losses from the flooded lands consist of deep percolation and flow through. Deep percolation is specified in the *Maximum Percolation Rate* parameter. This parameter is set in *Other Assumptions\Valley Floor Hydrology\Calibration Factors\Rice\MaxPercRate*. Flow through, for salinity control, and losses to surface drains are set by the *Release Requirement* parameter. Values for *Release Requirement* are read from the comma-separated values (csv) file SACVAL_Rice_Drainage.csv located in Data\Param\Rice.

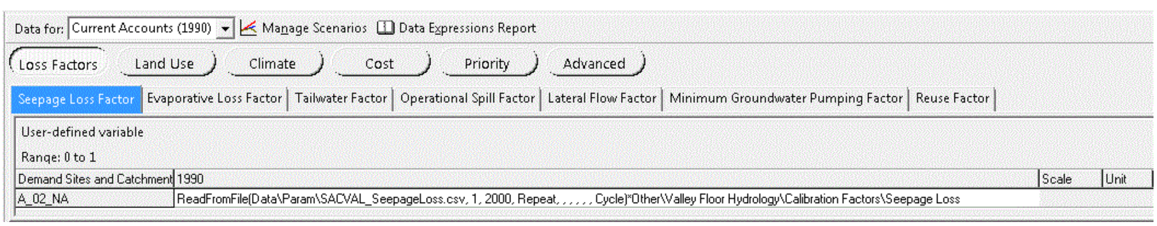
4.4.2 Loss Factors

Loss factors are entered at the DU level in the catchment interface, except for *Potential Application Efficiency*, *Loss to Groundwater*, and *Loss to System*. *Potential Application Efficiency* is listed by WBA and is entered into the *Other Assumptions\Valley Floor Hydrology\Potential Application Efficiency* branch of the model, and Loss to Groundwater and Loss to System are both entered as transmission losses in *Supply and Resources\Transmission Links\Loss to Groundwater* and *Supply and Resources\Transmission Links\Losses* branch of the model.

To maintain flexibility in adjusting model parameters, all loss factors are read into SacWAM using a read-from-file command that references a specific column in the relevant csv file. There are two ways to adjust these parameters, either by altering the factors within the csv file, or globally scaling a factor in the *Other Assumptions\Valley Floor Hydrology\Calibration Factors* branch. To decrease evaporative losses across the model by 20%, for instance, one would change the value of 1 in the *Other Assumptions\Valley Floor Hydrology\Calibration Factors\Evaporative Loss* branch to 0.8. The factors that can be adjusted in this way are: *Seepage Loss*, *Evaporative Loss*, *Tailwater*, *Operational Spill*, *Lateral Flow*, *Reuse*, and *Potential Application Efficiency*.

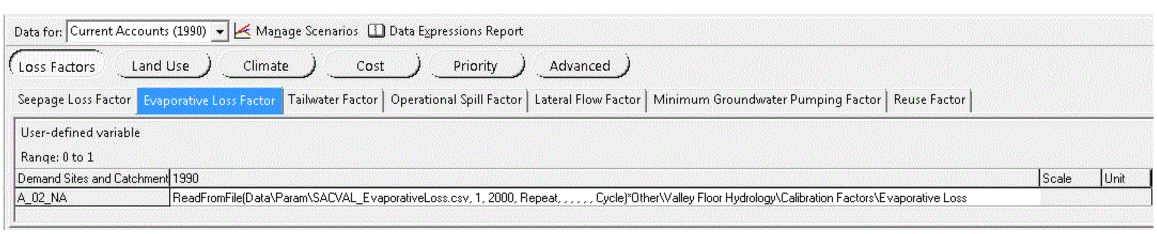
In the current version of SacWAM, loss factors are based on values derived for DWR models. All global factors are currently set to a value of 1.0.

4.4.2.1 *Seepage Loss Factor*



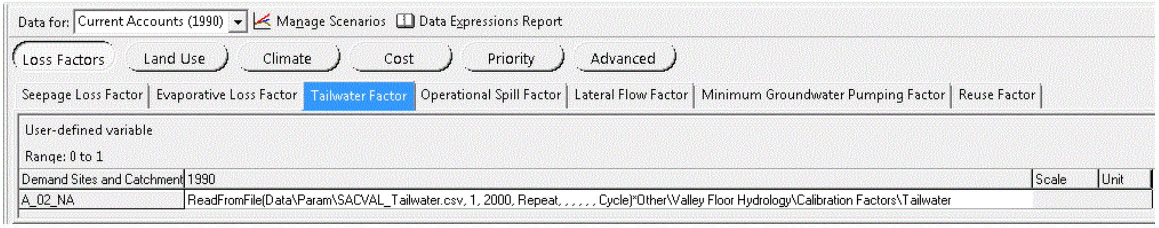
Seepage Loss is loss to the groundwater system from conveyance channels. Initial values were based on default DWR values. These values range from 0.0 to 0.28.

4.4.2.2 *Evaporative Loss Factor*



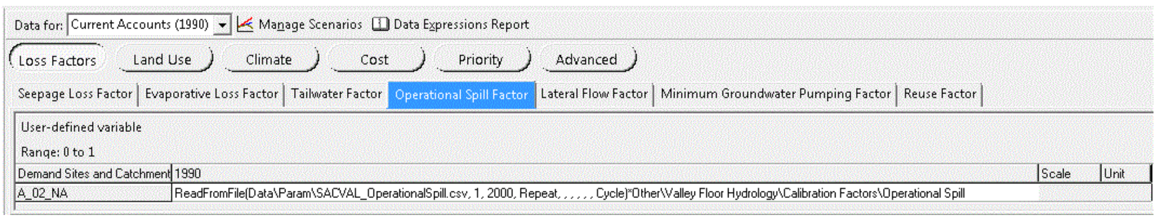
Evaporative Loss is defined as evaporative loss from surface water conveyance channels, including that from riparian growth adjacent to these channels. With the exception of the Delta DUs (DUs A_50_XXX), which have a value of zero, all DUs were assumed to have a value of 0.01.

4.4.2.3 *Tailwater Factor*



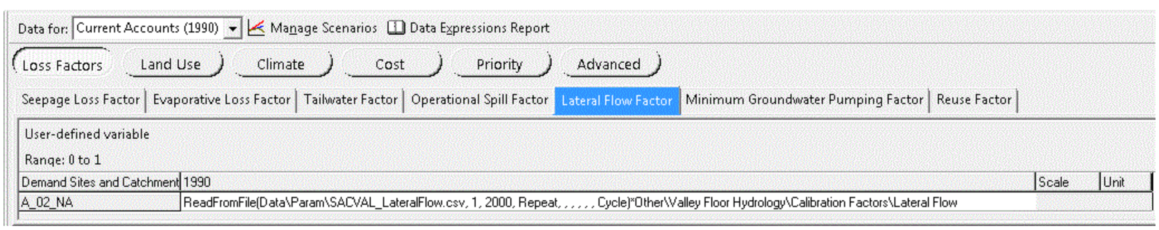
Tailwater factors are assumed to be 0.1, i.e., ten percent of applied water leaves the field as tailwater.

4.4.2.4 *Operational Spill Factor*



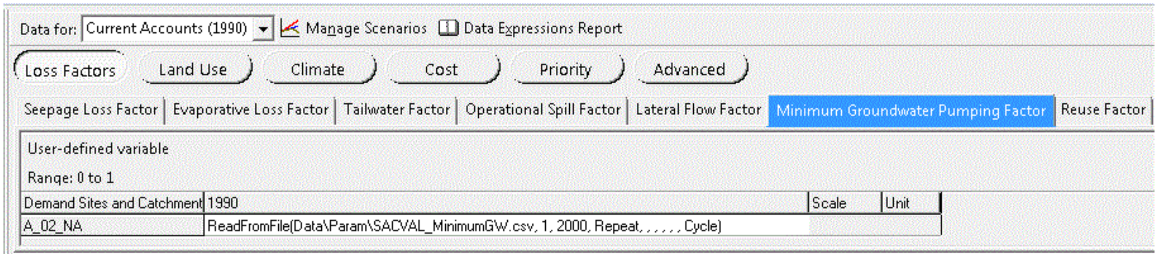
Operational spills associated with canal conveyance in agricultural and refuge DUs and are typically assumed to be three percent of the surface water diversion. However, for a few DUs where operational spills are known to be large (e.g. Anderson-Cottonwood ID), operational losses were increased up to a maximum of 25 percent of the diversion. For buried pipe systems, operational spills are assumed to be zero. These values were based on default DWR values.

4.4.2.5 *Lateral Flow Factor*



Lateral flow is horizontal seepage to the canal toe drains. The portion of lateral flow that is recaptured for irrigation is not represented explicitly in WEAP because this does not affect the water balance or water available at the farm gate. For WEAP, this recaptured water is simulated as remaining within the canal system. These values were based on default DWR values and range from 0.0 to 0.25.

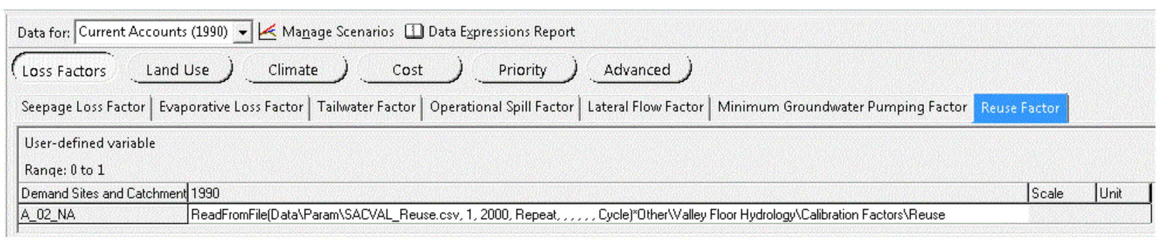
4.4.2.6 *Minimum Groundwater Pumping Factor*



Minimum **groundwater pumping** factors are specified in SacWAM representing the part of the applied water demand that must be met from groundwater pumping. Applied water demands in excess of minimum groundwater pumping are met from surface water and additional groundwater pumping, if necessary.

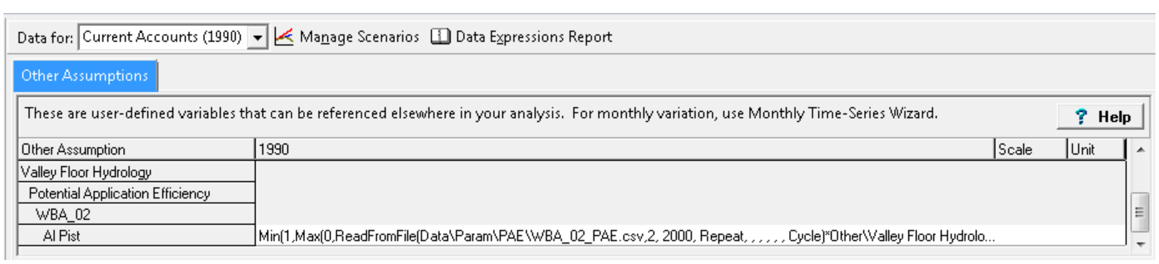
The *Minimum Groundwater Pumping Factor* was determined using information from DWR's county land use surveys (DWR, 1994a-b, 1995a-b, 1996, 1997b, 1998a-c, 1999a-b, 2000a). Initial groundwater pumping fractions were calculated as the lands dependent on groundwater only divided by the area of lands that 1) use surface water only 2) use groundwater only or 3) have access to both surface water and groundwater. Each agricultural and urban DU has a *Minimum Groundwater Pumping Factor* in SacWAM. This parameter is used to define the Maximum Flow Percent of Demand parameter on the surface water transmission links (Section 6.6).

4.4.2.7 *Reuse Factor*



Reuse of tailwater from crops other than rice is set equal to zero to ten percent of applied water demand.

4.4.2.8 *Potential Application Efficiency*



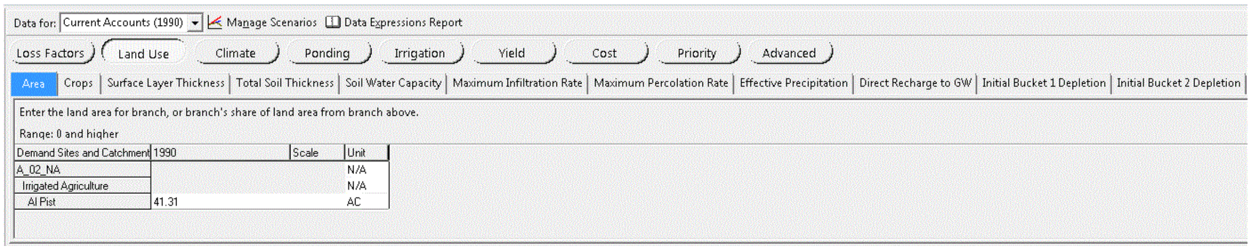
Potential application efficiencies are WBA- and crop-specific. They are discussed in this section as they relate to other Loss Factor parameters, although in SacWAM they are specified in the *Other*

Assumptions\Valley Floor Hydrology\Potential Application Efficiency branch of the model. These values are based on UC Davis (2013) and Sandoval-Solis et al. (2013).

4.4.3 Land Use

Under the *Agricultural Catchments\Land Use* branch, parameter values were set according to the descriptions provided below.

4.4.3.1 *Area*



The following are the data sources used in determining the distribution of area classes in SacWAM DUs:

- WD and WA boundaries and service areas obtained from the California Spatial Information Library (CaSIL), which comprises separate GIS layers for Federal, State, and private water-districts (CaSIL, 2013).
- County land use surveys undertaken by DWR's DSIWM, formerly Division of Planning and Local Assistance (DWR, 1994a-b, 1995a-b, 1996, 1997b, 1998a-c, 1999a-b, 2000a).
- County and regional integrated water resources plans and integrated water management plans.
- Reclamation CVP water supply contract renewal (Reclamation, 2013a) and supporting environmental documents (Assessments, Environmental Impact Statements, and Findings of No Significant Impacts) (Reclamation, 2013b).

To define SacWAM agricultural land acreages, DWR land use data were obtained (DWR, 1994a-b, 1995a-b, 1996, 1997b, 1998a-c, 1999a-b, 2000a). In the 1950s, DWR began to collect geospatial urban and agricultural land use data by county. Each county is surveyed every seven years. The DWR data include over seventy crop classifications. Due to the large number of classifications, crop types were aggregated where possible to create fewer land use classes for use in SacWAM (Table 4-9). The scheme includes twenty crop classifications in addition to classifications for urban (UR) and native vegetation (NV) areas. Note that the acreages given for wetland areas (DWR classes NR4 and NR5) are lumped with the NV class. The acreages given for wetland areas represent identified wetlands in agricultural areas, and were only identified in the upper half of the Sacramento Valley by the DWR Northern District office.

Table 4-9. SacWAM Agricultural Land Use Classifications

SacWAM Land Use Classification		DWR Land Use Classification	
Crop Type (Code)	**Abbreviation**	**Code**	**Description**
Alfalfa (AL)	Alfalfa	P1	Pasture: Alfalfa
Almonds & Pistachios (AP)	Al Pist	D12	Deciduous Fruits & Nuts: Almonds
		D14	Deciduous Fruits & Nuts: Pistachios
Corn (CR)	Corn	F6	Field Crops: Corn
Cotton (CO)	Cotton	F1	Field Crops: Cotton
Cucurbits (CU)	Cucurb	T9	Truck, Nursery, Berry: Melons, Squash, and Cucumbers
Dry Beans (DB)	DryBean	F10	Field Crops: Beans
Grain (GR)	Grain	G	Grain & Hay: Miscellaneous
		G1	Grain & Hay: Barley
		G2	Grain & Hay: Wheat
		G3	Grain & Hay: Oats
		G6	Grain & Hay: Miscellaneous Mixed
Native Vegetation and Refuges (NV)	Native Vegetation	E	Entry Denied
		I	Idle
		I1	Land not cropped in current or previous season, but cropped in past three years
		I2	New lands being prepared for crop production
		NB	Barren Land
		NB1	Dry Stream Channel
		NB2	Mine Tailing
		NB3	Native Barren
		NC	Native Classes Unsegregated
		NR	Riparian Vegetation
		NR1	Marsh
		NR2	High Water Table Meadow
		NR3	Trees and Shrubs
		NR4	Seasonal Duck Marsh
		N45	Permanent Duck Marsh
		NS	Not Surveyed
		NV	Native Vegetation
		NV1	Grass
		NV2	Light Brush
		NV3	Medium Brush
		NV4	Heavy Brush
		NV5	Brush and Timber
		NV6	Forest
		NW	Water Surface
Onions and Garlic (OG)	On Gar	T10	Truck, Nursery, Berry: Onions and Garlic
Other Deciduous Orchard (OR)	Oth Dec	D	Deciduous Fruits & Nuts: Not Classified
		D1	Deciduous Fruits & Nuts: Apples
		D2	Deciduous Fruits & Nuts: Apricots
		D3	Deciduous Fruits & Nuts: Cherries
		D5	Deciduous Fruits & Nuts: Peaches and Nectarines
		D6	Deciduous Fruits & Nuts: Pears
		D7	Deciduous Fruits & Nuts: Plums
		D8	Deciduous Fruits & Nuts: Prunes
		D9	Deciduous Fruits & Nuts: Figs
		D10	Deciduous Fruits & Nuts: Miscellaneous Deciduous
		D13	Deciduous Fruits & Nuts: Walnuts

Table 4-9. SacWAM Agricultural Land Use Classifications cont.

SacWAM Land Use Classification		DWR Land Use Classification	
Crop Type (Code)	**Abbreviation**	**Code**	**Description**
Other Field (FI)	Oth Fld	F	Field Crops: Not Classified
		F3	Field Crops: Flax
		F4	Field Crops: Hops
		F7	Field Crops: Sorghum
		F8	Field Crops: Sudan
		F11	Field Crops: Miscellaneous Field
		F12	Field Crops: Sunflowers
Pasture (PA)	Pasture	P	Pasture: Not Classified
		P2	Pasture: Clover
		P3	Pasture: Mixed
		P4	Pasture: Native
		P5	Pasture: High Water Native
		P6	Pasture: Miscellaneous Grasses
		P7	Pasture: Turf Farms
Potatoes (PO)	Potato	T12	Truck, Nursery, Berry: Melons, Squash, and Cucumbers
Rice (RI)	Rice and Rice Early	R	Rice: Rice
Safflower (SF)	Safflwr	F2	Field Crops: Safflower
Subtropical (SO)	Subtrop	C	Citrus & Subtropical: Not Classified
		C1	Citrus & Subtropical: Grapefruit
		C2	Citrus & Subtropical: Lemons
		C3	Citrus & Subtropical: Oranges
		C4	Citrus & Subtropical: Dates
		C5	Citrus & Subtropical: Avocados
		C6	Citrus & Subtropical: Olives
		C7	Citrus & Subtropical: Misc. Subtropical
		C8	Citrus & Subtropical: Kiwis
		C9	Citrus & Subtropical: Jojoba
		C10	Citrus & Subtropical: Eucalyptus
Sugar Beets (SB)	SgrBeet	F5	Field Crops: Sugar Beets
Tomatoes (TM: TH)	Pr Tom; Fr Tom	T15	Truck, Nursery, Berry: Tomatoes
Urban (UR)	Urban	S1	Semi-agricultural: Farmsteads
		S2	Semi-agricultural: Livestock Feed Lots
		S3	Semi-agricultural: Dairies
		S4	Semi-agricultural: Poultry Farms
		U	Urban: Not Classified
		UC	Urban Commercial: Not Classified
		UC1	Urban Commercial: Offices, Retailers
		UC2	Urban Commercial: Hotels
		UC3	Urban Commercial: Motels
		UC4	Urban Commercial: Recreation Vehicle Parking, Camping
		UC5	Urban Commercial: Institutions
		UC6	Urban Commercial: Schools
		UC7	Urban Commercial: Municipal Auditoriums, Stadiums, Theaters
		UC8	Urban Commercial: Misc. High Water Use
		UI	Urban Industrial: Not Classified
		UI1	Urban Industrial: Manufacturing, Assembling and Processing
		UI2	Urban Industrial: Extractive Industries
		UI3	Urban Industrial: Storage and Distribution
		UI6	Urban Industrial: Saw Mills
		UI7	Urban Industrial: Oil Refineries
		UI8	Urban Industrial: Paper Mills
		UI9	Urban Industrial: Meat Packing Plants

Table 4-9. SacWAM Agricultural Land Use Classifications cont.

SacWAM Land Use Classification		DWR Land Use Classification	
Crop Type (Code)	**Abbreviation**	**Code**	**Description**
Urban (UR)	Urban	UI10	Urban Industrial: Steel and Aluminum Mills
		UI11	Urban Industrial: Fruit and Vegetable Canneries
		UI12	Urban Industrial: Misc. High Water Use
		UI13	Urban Industrial: Sewage Treatment Plant/Ponds
		UI14	Urban Industrial: Waste Accumulation Sites
		UI15	Urban Industrial: Wind/Solar Farms
		UL	Urban Landscape: Not Classified
		UL1	Urban Landscape: Lawn Area (irrigated)
		UL2	Urban Landscape: Golf Course (irrigated)
		UL3	Urban Landscape: Ornamental Landscape (irrigated)
		UL4	Urban Landscape: Cemeteries (irrigated)
		UL5	Urban Landscape: Cemeteries (not irrigated)
		UR	Urban Residential: Not Classified
		UR1	Urban Residential: Single Family (1-5 acres)
		UR2	Urban Residential: Single Family (1-8 units/acre)
		UR3	Urban Residential: Multi Family
		UR4	Urban Residential: Trailer Courts
		UR11	Urban: Residential, Single Family (1-5 acres), <25% irrigated
		UR13	Urban: Residential, Single Family (1-5 acres), 51%-75% irrigated
		UV	Urban Vacant: Not Classified
		UV1	Urban Vacant: Unpaved Areas
		UV3	Urban Vacant: Railroad Right-Of-Way
		UV4	Urban Vacant: Paved Areas
		UV6	Urban Vacant: Airport Runways
Vineyards (VI)	Vine	V	Vineyard: Not Classified
		V1	Vineyard: Table Grapes
		V2	Vineyard: Wine Grapes
		V3	Vineyard: Raisin Grapes

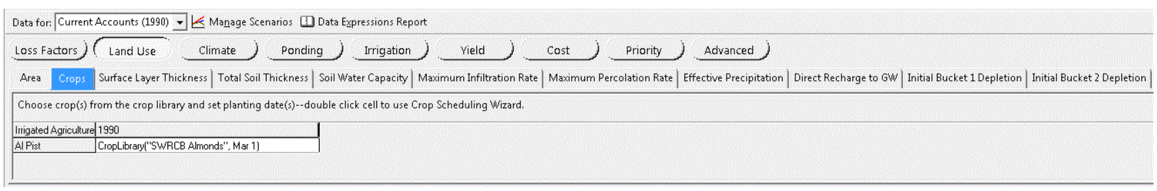
Once SacWAM land use classes were determined, acreages for each class were found. Irrigated crop acreage (ICA) of DAUs from water years 1998-2007 were obtained from DSIWM. The average annual ICA for this 10-year period was assumed to be representative of "existing conditions." Then, a "snapshot" of land use for the Central Valley was assembled from the county land use surveys to create a continuous mosaic in GIS, although the land use data are derived from different years. The GIS mosaic was intersected with DU polygons and with DAU polygons to obtain the historical irrigated land area for each DU and for each DAU. These historical values were converted to a value representing "existing conditions" by scaling the "snapshot" land use data to match the 10-year DAU value. The following example illustrates this process:

1. Assume the 10-year historical average for wheat in DAU X=10,000 acres
2. Assume the GIS data from the land use mosaic shows 8,000 acres of wheat in DAU X
3. Assume the GIS data from the land use mosaic shows 500 acres of wheat in DU A
4. If DU A is located within DAU X, the existing level acreage for wheat=500*(10,000/8,000) acres

A table was created containing acreage data for each SacWAM DU, displayed in twenty-four columns. Each column indicates the acreage of a specific crop within a DU, listed by its crop code. For instance, "A_02_NA_AL" will contain the acreage of alfalfa in catchment "A_02_NA." There are instances where irrigated land exists inside municipal boundaries which are represented by an urban DU. In this case, the irrigated land was removed from the urban DU and associated with a neighboring agricultural DU. For example, “A_02_NA” may supply water to neighboring demand site “U_02_SU” for 500 acres of alfalfa. Consequently, the crop acreage of “A_02_NA_AL” will be larger than the irrigated alfalfa physically present in “A_02_NA,” because it includes the alfalfa acreage of “U_02_SU.” It is also the case that agricultural catchments include urban area. These areas include semi-agricultural, industrial and commercial lands that exist outside of municipal boundaries, such as schools, motels, and mills. These areas are simulated using parameters that reflect mostly impermeable surfaces in SacWAM. The final land use dataset for all agricultural lands except for the Delta DUs (A_50_NA1 through A_50_NA7) is contained in the **agricultural land use** file.

The land use dataset for areas within the Sacramento–San Joaquin Delta is documented in the **delta land use** file. A similar approach as described above was used to determine land use acreages in the Delta. In 2006, the Delta Evapotranspiration of Applied Water model (DETAW) was developed by the University of California at Davis to estimate consumptive water demands within the Delta (Kadir, 2006). This development was in cooperation with DSIWM and funded by the Modeling Support Branch of the Bay-Delta office. DETAW estimates consumptive water demands for 168 subareas within the Delta Service Area. To determine land use acreage for the Delta, a shapefile containing these 168 DETAW subregions (DWR, 2014b) was intersected with DWR’s land use survey of Delta lands (DWR, 2007). A look-up table was used to associate each of the DETAW subregions with its SacWAM DU. The result of this process was land use data by crop type for each DU.

4.4.3.2 *Crops*



The Crops parameter is used to specify crop type and planting date. WEAP has a **crop library** (General>Crop Library) where information on crop coefficients, season length, management allowable depletion, and rooting depth is contained. The twenty-two SacWAM crops, plus Native Vegetation and Urban classes were added to the **crop library**. The planting date information entered into the Crop Library were obtained from the DWR Consumptive Use Program (CUP) and Simulation of Evapotranspiration of Applied Water (SIMETAW) models (Orang et al., 2013). The crop coefficients were calibrated to match crop ET values produced by the CUP model. Rooting depth, depletion factors, and maximum height information were obtained from the WEAP database which is based on FAO56 (Allen et al., 1998).

4.4.3.3 *Direct Recharge to GW*

Direct Recharge to GW was assumed to be equal to 0 percent as this feature of the WEAP software was not used.

4.4.3.4 *Effective Precipitation*

A modified SCS Curve Number approach (NRCS, 1986; SCS, 1972) was used to partition the daily rainfall into runoff and infiltration. The modification to the standard approach was the make the maximum soil moisture retention, S, a function of the soil moisture at the end of the previous day (Schroeder et al., 1994).

The effective precipitation is calculated as:

$$P_{eff} = \frac{P-Q}{P}\ x\ 100 \qquad \text{Equation 4-16}$$

where:

P_{eff} = effective precipitation (%)
Q = runoff (in)
P = precipitation (in)

Runoff is calculated using:

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)} \qquad \text{Equation 4-17}$$

where:

S = maximum soil moisture retention (in)

These equations are calculated in the Effective Precipitation parameter of the interface. The expression requires the value of the maximum soil moisture retention, S, which is calculated as a function of the current soil moisture status and is described in the Max Soil Moisture Retention parameter definition.

4.4.3.5 *Initial Bucket 1 Depletion*

Initial Bucket 1 Depletion was assumed to be equal to 0 mm (the WEAP default value).

4.4.3.6 *Initial Bucket 2 Depletion*

Initial Bucket 2 Depletion was assumed to be equal to 0 mm (the WEAP default value).

4.4.3.7 *Max Soil Moisture Retention*

The maximum soil moisture retention, S, is calculated using:

$$S = \begin{bmatrix} S_m \left[1 - \frac{SM-[(FC+WP)/2]}{UL-[(FC+WP)/2]}\right] & for\ SM > (FC+WP)/2 \\ S_m & for\ SM < (FC+WP)/2 \end{bmatrix} \qquad \text{Equation 4-18}$$

where:

S_m = maximum value of S where S = 1000/CN – 10, in inches

SM = soil moisture at the end of the previous day

FC = field capacity of soil

WP = wilting point of soil

UL = soil saturation

Making the maximum soil moisture retention a function of the soil moisture results in increasing runoff as soil moisture increases. The expressions for *Max Soil Moisture Retention* and *Effective Precipitation* are located in the **effective precipitation** spreadsheet.

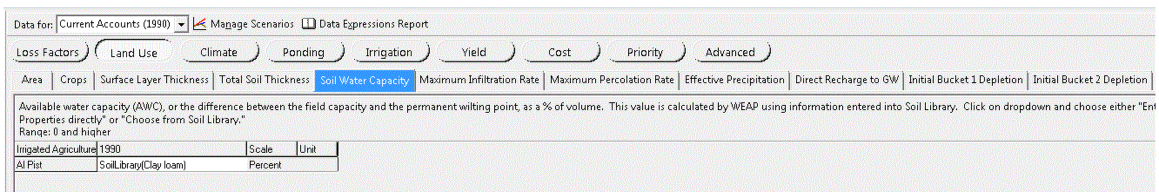
4.4.3.8 *Maximum Infiltration Rate*

The Maximum Infiltration Rate was not specified.

4.4.3.9 *Maximum Percolation Rate*

The Maximum Percolation Rate was specified to 0.025 inches/day for rice based on information from the UC Davis Cooperative Extension. This value is set in *Other Assumptions\Valley Floor Hydrology\Calibration Factors\Rice\MaxPercRate* for Rice and Rice Early. A maximum percolation rate was not set for other crops.

4.4.3.10 *Soil Water Capacity*



Soil water capacity is plant available water calculated as the difference between field capacity and permanent wilting point. This value is specified in the Soil Library (General>Soil Library). All soils were assumed to be clay loam with an available water capacity of 14.5%. This assumption was based on an analysis of **surface soils** in the STATSGO database that found loam and clay loam are the dominant surface soil textures on the Sacramento Valley floor.

4.4.3.11 *Surface Layer Thickness*

Surface Layer Thickness was assumed to be equal to 0.1 m (the WEAP default value). This is the portion of the soil from which bare soil evaporation can extract water.

4.4.3.12 *Total Soil Thickness*

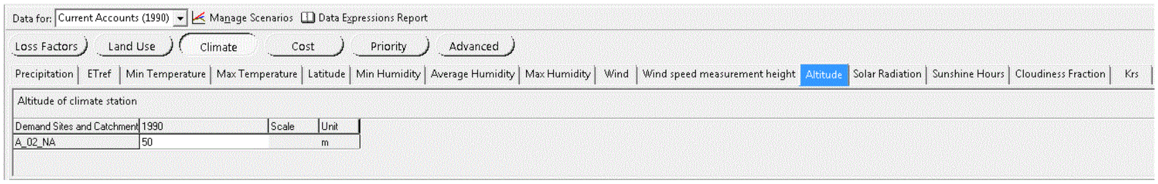
Total Soil Thickness was assumed to be equal to 2 m (the WEAP default value). Transpiration can remove moisture from the depth of soil penetrated by roots (specified in the Crop Library), this parameter specifies the total depth over which the soil moisture balance is calculated.

4.4.3.13 *Fraction Covered*

Fraction Covered is used to specify the fraction of the soil that is covered by crop. This value is used to determine the portion of the soil that should be subjected to bare soil evaporation. If this parameter is left blank then MABIA uses an algorithm found in FAO56 that calculates the covered fraction as a function of crop development stage and maximum crop height. In SacWAM this value has been specified for three crops. Alfalfa and pasture were given values of 1.0 since they maintain complete cover year round. Rice was given a value of 1.0 during the rice growing season. This forces the MABIA model to calculate rice ET as the product of the basal crop coefficient and the reference ET. It eliminates all bare soil evaporation. By substituting the literature based single crop coefficient for the basal crop coefficient, the model was forced to calculate the rice ET at the rate specified in the literature (Linquist et al., 2015).

4.4.4 Climate

4.4.4.1 Altitude



This parameter was specified for the valley floor catchments that use the MABIA calculation algorithm. This value was assumed to be 50 m for all catchments.

4.4.4.2 Average Humidity

No data were input for *Average Humidity*, because *Minimum Humidity* and *Maximum Humidity* were both specified.

4.4.4.3 Cloudiness Fraction

No data were input for the *Cloudiness Fraction*. It was assumed that errors introduced by this assumption are minimal since there is little cloudiness during the period of highest ET (Apr – Oct).

4.4.4.4 ETref

No data were input for *ETref*, because SacWAM uses the Penman-Monteith equation to calculate *ETref*.

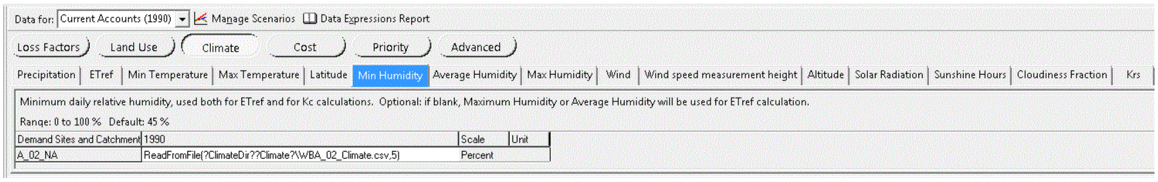
4.4.4.5 Krs

Krs is not used in SacWAM as the Penman Monteith equation is used to calculate *ETref.*

4.4.4.6 Latitude

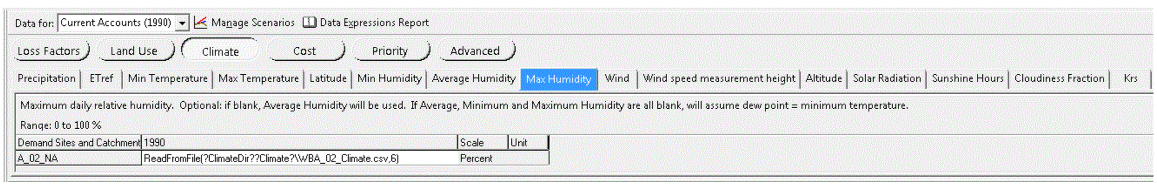
Centroids were calculated in ArcGIS for all DUs and catchments after DUs and catchments had been dissolved into multi-part features. This allowed the calculation of one centroid per DU and catchment rather than one centroid per DU or catchment part. Latitudes were calculated for these points in decimal degrees in WGS1984 UTM Zone 11 N. **Latitudes** were rounded to three decimal places and imported into WEAP.

4.4.4.7 *Min Humidity*



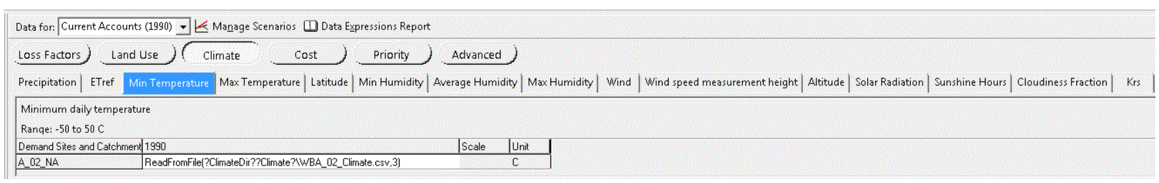
This dataset is read from a csv file located in the model data directory specified in *Key Assumptions\ClimateDir*. The model data directory is located within the Area directory and is called "Data." These data were derived using the approach discussed in Section 4.3.

4.4.4.8 *Max Humidity*



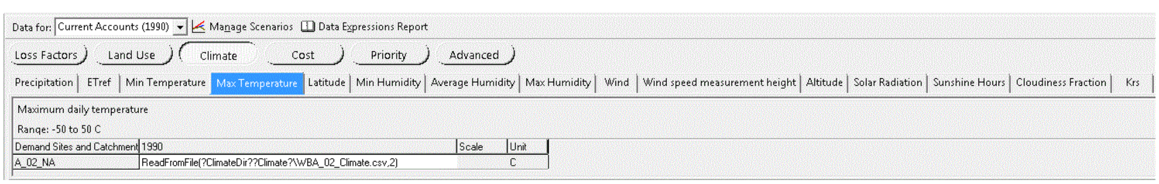
This dataset is read from a csv file located in the model data directory specified in *Key Assumptions\ClimateDir*. The model data directory is located within the Area directory and is called "Data." These data were derived using the approach discussed in Section 4.3.

4.4.4.9 *Min Temperature*



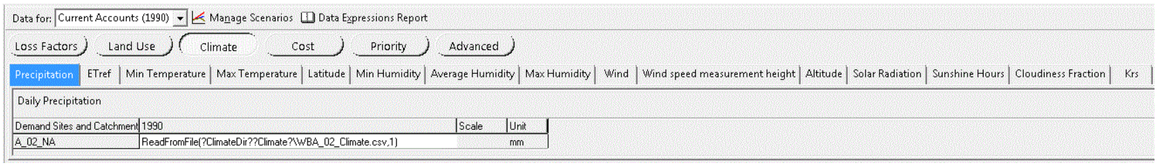
This dataset is read from a csv file located in the model data directory specified in *Key Assumptions\ClimateDir*. The model data directory is located within the Area directory and is called "Data." These data were derived using the approach discussed in Section 4.3.

4.4.4.10 *Max Temperature*



This dataset is read from a csv file located in the model data directory specified in *Key Assumptions\ClimateDir*. The model data directory is located within the Area directory and is called "Data." These data were derived using the approach discussed in Section 4.3.

4.4.4.11 *Precipitation*



This dataset is read from a csv file located in the model data directory specified in *Key Assumptions\ClimateDir*. The model data directory is located within the Area directory and is called "Data." These data were derived using the approach discussed in Section 4.3.

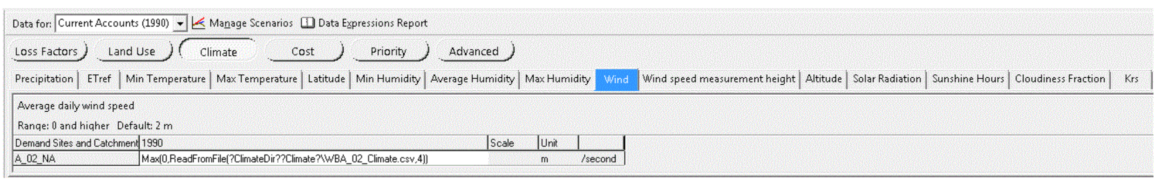
4.4.4.12 *Solar Radiation*

No value for solar radiation was entered; it was calculated in the MABIA module using the minimum and maximum daily temperature and the Hargreaves formula (Hargreaves and Samani, 1985).

4.4.4.13 *Sunshine Hours*

No data were input for *Sunshine Hour*s as it is not required.

4.4.4.14 *Wind*



This dataset is read from a csv file located in the model data directory specified in *Key Assumptions\ClimateDir*. The model data directory is located within the Area directory and is called "Data." These data were derived using the approach discussed in Section 4.3.

4.4.4.15 *Wind Speed Measurement Height*

The *Wind speed measurement height* was set to 2 m which is the standard used in the Penman Monteith Equation.

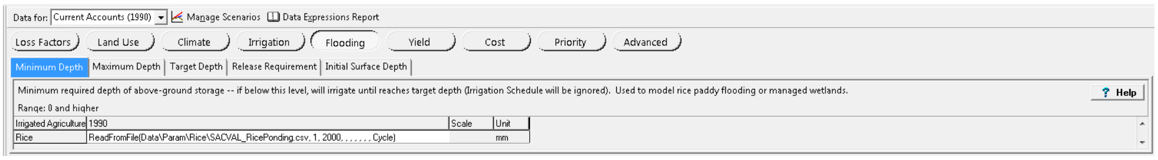
4.4.5 Flooding

Minimum Depth, Maximum Depth, and *Target Depth* were specified in SacWAM only for rice and flooded wetlands in refuge areas.

The timing and magnitude of rice flooding was based on a **rice management description** written by Todd Hillaire of DWR. The flooding pattern begins with a pre-planting irrigation used to saturate the soil and pond water to a depth of 3 inches. This irrigation starts five days prior planting day. Following planting the water is allowed to drain. After plant emergence, water is ponded to a depth of 5 inches (125 mm) on May 26. This depth is maintained until July 1 at which point the depth is increased to a depth of 8 inches (200 mm) by July 31. This depth is maintained until the end of August at which point the field is allowed to drain until September 15. For early rice, this pattern is shifted 3 weeks earlier.

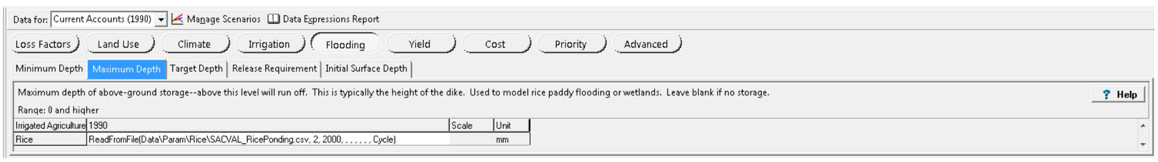
During the winter months the fields are flooded to promote rice-straw decomposition and to attract waterfowl. In SacWAM this flooding is assumed to start on October 15 and reach a *Target Depth* of 3 inches by January 1. Rainfall is allowed to collect in the fields up to a depth of 8 inches. Starting January 15 no more water is added to the fields. During the first two weeks of March the fields are actively drained to a depth of zero inches.

4.4.5.1 *Minimum Depth*



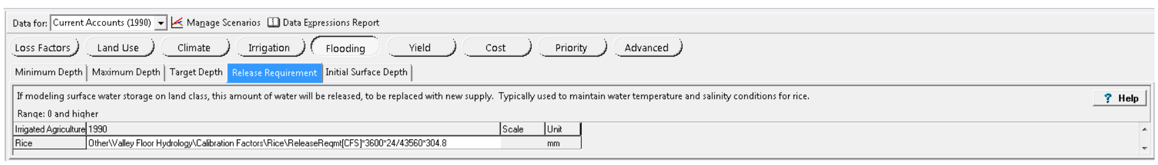
The minimum depth was specified using the timeseries described above.

4.4.5.2 *Maximum Depth*



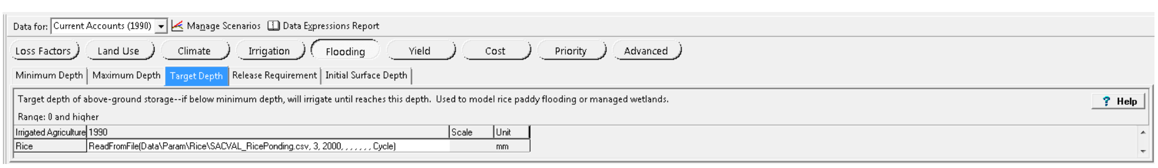
The maximum depth was specified using the timeseries described above with the exception at the end of the rice season this value was kept at 8 inches (200 mm) to allow the ponded water to dissipate due to evaporation and deep percolation.

4.4.5.3 *Release Requirement*



This value was initially set at 2.275 mm/d to represent the continuous flow of water through the rice paddies that is used to control the salt concentration. During calibration this value was adjusted for some regions. These values can be found in SACVAL_Rice_Drainage.csv located in Data\Param\Rice.

4.4.5.4 *Target Depth*



The target depth was set using the timeseries described above.

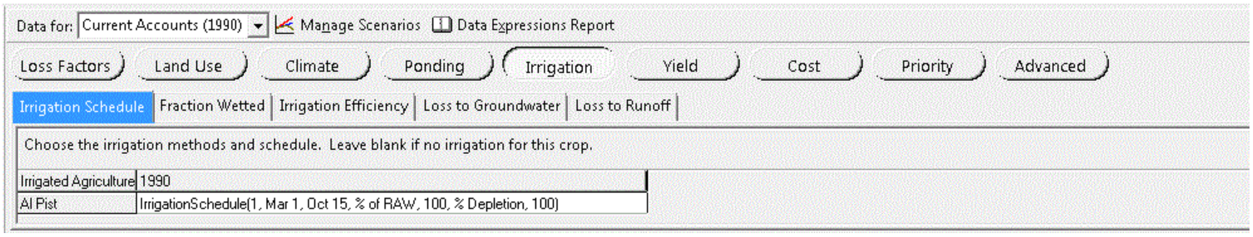
4.4.5.5 *Initial Surface Depth*

The flooding depth at the beginning of the water year is assumed to be 0 mm for all crops and non-irrigated areas in agricultural catchments.

4.4.6 Irrigation

Fraction Wetted, Irrigation Efficiency, Irrigation Schedule, Loss to Groundwater, and *Loss to Runoff* were specified in SacWAM.

4.4.6.1 *Irrigation Schedule*

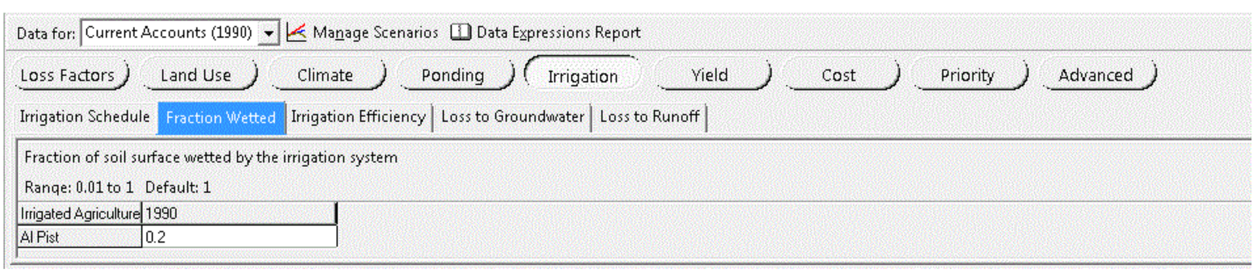


The irrigation schedule is used to enter parameters that control irrigation management. Multiple schedules can be entered if management varies over the growing season. In SacWAM all crops use one irrigation schedule. The information in the schedule includes:

1. The starting day (within the growing season) for which the parameters will apply. In SacWAM this is set to the first day of the growing season.
2. The ending day (within the growing season) for which the parameters will apply. In SacWAM this is set to the last day of the irrigation season.
3. The irrigation trigger. In SacWAM this is set to 100% of the Readily Available Water. The Readily Available Water is the portion of the Available Water Capacity that is usable by the plant without it experiencing water stress.
4. The irrigation amount. In SacWAM this is set to 100% of the depleted water. This means that irrigation will be sufficient to increase soil moisture to field capacity.

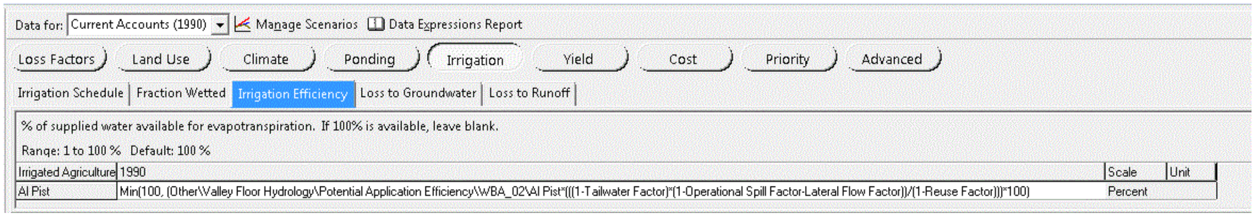
The exception to this is rice. Rice is irrigated if the Target Depth is non-zero and the ponding depth is less than the minimum depth. The irrigation schedule is ignored.

4.4.6.2 *Fraction Wetted*



The **fraction wetted** parameter sets the fraction of the soil that is wetted by an irrigation. This value is a function of the type of irrigation. A range of values from 0.3 to 1.0 is provided in Table 20 of FAO 56 (Allen et al., 1998). In SacWAM the values range from 0.2 for mature orchards to 0.75 for truck crops commonly irrigated with furrow irrigation. These values were set using the dominant irrigation technology found in the county land use reports (DWR, 1994a-b, 1995a-b, 1996, 1997b, 1998a-c, 1999a-b, 2000a). For flooded rice, this value is set to 1.0 automatically.

4.4.6.3 *Irrigation Efficiency*



An **irrigation efficiency** is entered at the crop level for each DU, as shown above. *Irrigation Efficiency* is defined in WEAP as the percentage of supplied water available for ET. The following equation is used to calculate this parameter, and its value is constrained between 0 and 100 percent in SacWAM.

$$\textit{Irrigation Efficiency}\ (\%) = \text{PAE}.\frac{(1 - f_{TW}).(1 - f_{OS} - f_{LF})}{(1 - f_{RU})} \qquad \text{Equation 4-19}$$

where:

PAE= Potential Application Efficiency

f_{TW}= Tailwater Factor

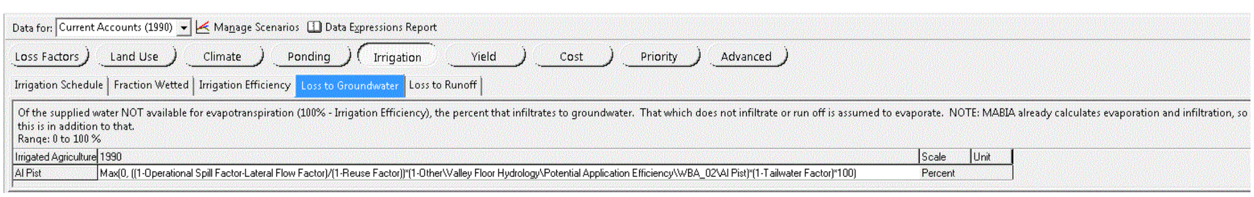
f_{os}= Operational Spill Factor

f_{LF}= Lateral Flow Factor

f_{RU}= Reuse Factor

Note: these factors are defined above in the Conceptual Framework section. For rice, the irrigation efficiency parameter is not used.

4.4.6.4 *Loss to Groundwater*



Loss to groundwater is entered at the crop level for each DU. It is defined as the percent of supplied water not available for ET (100% Irrigation Efficiency) that infiltrates to groundwater. The following equation is used to calculate this parameter, and its value is constrained between 0 and 100 percent in SacWAM.

$$\textit{Loss to Groundwater}\ (\%) = \frac{(1-f_{OS}-f_{LF})}{(1-f_{RU})} \cdot (1-PAE) \cdot (1-f_{TW}) \qquad \text{Equation 4-20}$$

where:

f_{os}= Operational Spill Factor

f_{LF}= Lateral Flow Factor

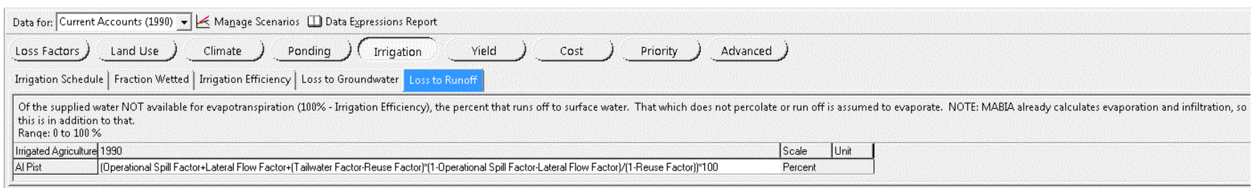
f_{RU}= Reuse Factor

PAE= Potential Application Efficiency

f_{TW}= Tailwater Factor

Note: these factors are defined above in the Conceptual Framework section. For flooded rice, this parameter is not used.

4.4.6.5 *Loss to Runoff*



Loss to runoff is entered at the crop level for each DU. It is defined as the percent of supplied water not available for ET (100%-Irrigation Efficiency) that runs off as surface water. The following equation is used to calculate this parameter, and that value is constrained between 0 and 100 percent in SacWAM.

$$\textit{Loss to Runoff}\ (\%) = f_{OS} + f_{LF} + (f_{TW} - f_{RU}).(1 - f_{OS} - f_{LF})/(1-f_{RU}) \qquad \text{Equation 4-21}$$

where:

f_{os}= Operational Spill Factor (as defined in as defined in 2.3.1.1 Loss Factors)

f_{LF}= Lateral Flow Factor (as defined in as defined in 2.3.1.1 Loss Factors)

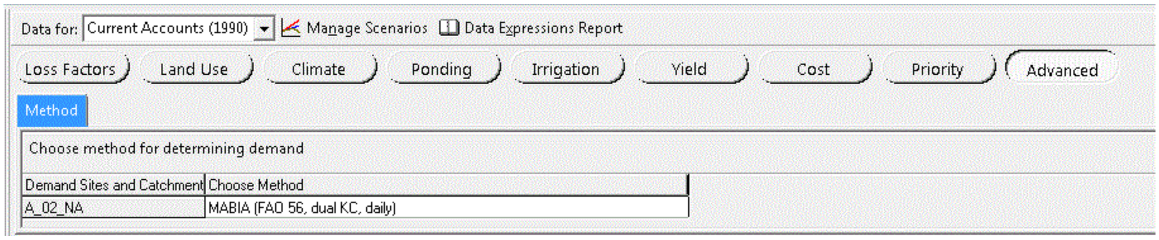
f_{TW}= Tailwater Factor (as defined in as defined in 2.3.1.1 Loss Factors)

f_{RU}= Reuse Factor (as defined in as defined in 2.3.1.1 Loss Factors)

Note: for flooded rice, this parameter is not used.

4.4.7 Advanced

4.4.7.1 *Method*



This is the screen in the WEAP interface where the calculation method for rainfall runoff and irrigation management is selected. In the case of the valley floor catchments, the MABIA crop water demand model was selected.

4.5 Refuge Catchment Parameters

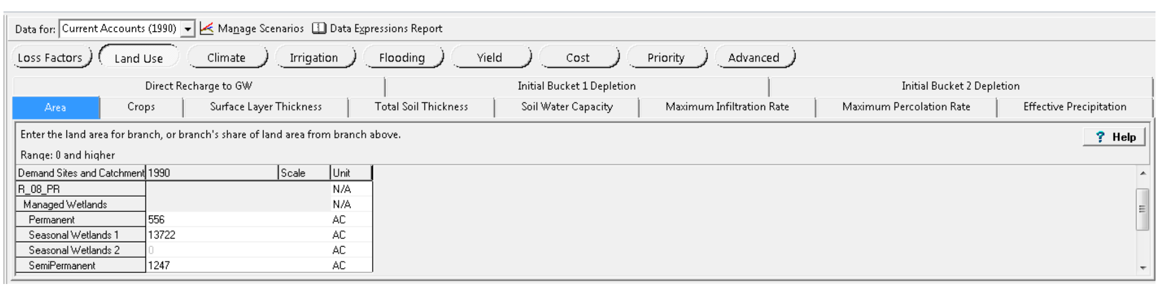
The refuge catchments in SacWAM simulate the management of wildlife refuges including the flooding of permanent, semi-permanent, and seasonal wetlands. Location information for datasets relating to these parameters is contained in Table 4-16.

4.5.1 Loss Factors

Loss associated with water deliveries to refuge catchments is treated in the same way as for agricultural catchments. See Section 4.4 for details.

4.5.2 Land Use

4.5.2.1 *Area*



The following are the data sources used to calculate **refuge land use** areas in SacWAM:

- Water Management Plans (Reclamation, 2011a-b)
- California Water Plan (DWR, 2005) and Update (DWR, 2009b)
- Butte and Sutter Basins Water Data Atlas (DWR, 1994c)
- Sacramento, Delevan, Colusa and Sutter NWRs Draft Comprehensive Conservation Plan (USFWS, 2008a)

Four SacWAM wetland classes are used to represent refuge habitat acreage, in addition to an "Uplands" class. These include: Permanent, SemiPermanent, Seasonal 1, and Seasonal 2. Many refuges and wildlife areas include multiple class types. The classes have distinct management practices, each making favorable habitat for specific species.

Permanent

Permanent wetlands are kept flooded year-round, but are drawn down every few years to recycle nutrients, increase productivity and discourage carp populations. Water depths in permanent wetlands vary throughout the year due to precipitation patterns, but a permanent wetland will be flooded during every month of the year. Permanent wetlands serve as habitat for egrets, heron, and other fish-eating birds.

SemiPermanent

Semi-permanent wetlands are kept flooded ten months of the year (October through July) and provide wetland habitat during summer months when seasonal wetlands are not flooded. These wetlands are more productive than permanent wetlands because they have a drying cycle. Semi-permanent wetlands are flooded so that the water depth is between four and twelve inches in order to allow ducks and other water birds access to food.

Seasonal 1

Seasonal wetlands are kept flooded from October 1 to January 15 and are managed to grow seed and produce invertebrates for migratory waterfowl and shorebirds. They are typically shallow, and include plants such as swamp timothy and watergrass.

Seasonal 2

The second class of seasonal wetlands are kept flooded from September 1 to January 15 and are also managed to grow seed and produce invertebrates for migratory waterfowl and shorebirds.

Uplands

The “Uplands” SacWAM class contains terrestrial refuge habitat. This class contains non-flooded lands as well as roads and buildings within the refuges.

Refuge acreages were determined for federal and state refuge and wildlife areas. These data were extracted from a variety of sources. Where possible, Water Management Plans (Reclamation, 2011a-b) were used to determine the habitat acreage within NWRs and WAs. These plans exist for most national refuges, and include tables containing habitat types with their associated 2010 acreages. Table 4-10 provides information on the aggregation of Urban Water Management Plan (UWMP) habitat types into SacWAM classes.

Table 4-10. Urban Water Management Plan Habitat Types

SacWAM Class	UWMP Habitat Types
Permanent	Permanent wetland
SemiPermanent	Semi-permanent wetland/brood pond
Seasonal	Seasonal wetland – timothy (not irrigated) Seasonal wetland – timothy (irrigated) Seasonal wetland – smartweed Seasonal wetland – watergrass
Reverse	Reverse cycle wetlands
Uplands	Riparian Irrigated pasture Upland (not irrigated) Upland (managed) Upland (grains) Roads, buildings, etc. Miscellaneous habitat Other

The Sacramento, Delevan, Colusa and Sutter Draft Comprehensive Conservation Plan (USFWS, 2008a) was used to determine habitat acreage in Sutter NWR. The Draft Comprehensive Conservation Plan includes a map of Sutter NWR (Figure 9), with polygons of twelve different habitat types and their associated acreages. These acreages were aggregated into SacWAM refuge classes (Table 4-11).

Table 4-11. Sacramento, Delevan, Colusa, and Sutter Draft Comprehensive Plan Habitat

SacWAM Class	Draft Comprehensive Conservation Plan Habitats
Permanent	Permanent pond
SemiPermanent	Summer water
Seasonal	Seasonal flooded marsh Watergrass
Reverse	--
Uplands	Unclassified Mixed riparian Valley oak riparian Water Annual grassland Unmanaged freshwater wetland Perennial grassland Cottonwood willow

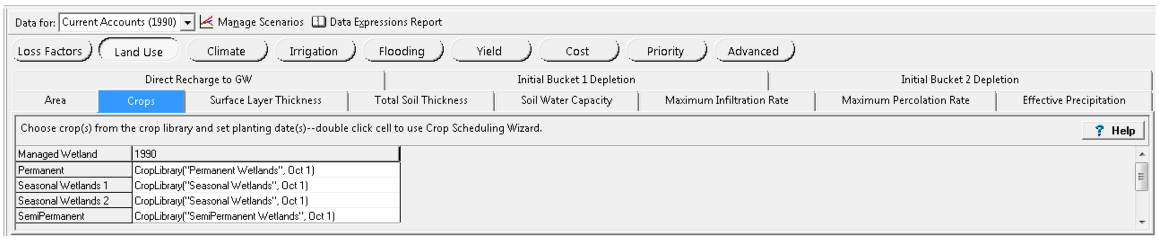
To determine habitat acreages for the Sutter and Butte Sink Duck Clubs, the Butte and Sutter Basins Water Data Atlas (DWR, 1994a) was used. In GIS, the map was overlaid on a parcel map and the various land holdings were analyzed. It was determined that all acreage in the Sutter and Butte Sink Duck Clubs should be considered “Seasonal” wetlands in SacWAM.

Habitat acreages for California wildlife areas are given in the California Water Plan (DWR, 2005) and Update (DWR, 2009b). These data are based on correspondence between DWR’s regional offices and wildlife area managers. Table 4-12 indicates how DWR habitat acreages are represented in SacWAM.

Table 4-12. DWR Habitat Classification

SacWAM Class	DWR Habitat
Permanent	Permanent ponds
SemiPermanent	Summer water
Seasonal	Seasonal marsh
	Watergrass
	Swamp timothy
	Smartweed
Reverse	Winter decomp
Uplands	--

4.5.2.2 *Crops*



Permanent, semi-permanent, seasonal 1 and seasonal 2 wetlands crop types were added to the **crop library**. These “crop” types were given a season length of 365 days and a crop coefficient of 1.0.

4.5.2.3 *Maximum Percolation Rate*

A *Maximum Percolation Rate* for Managed Wetlands was set at 0.025 in/day through *Other Assumptions\Valley Floor Hydrology\Calibration Factors\ Rice\MaxPercRate*. No maximum percolation rate was set for Uplands.

4.5.2.4 *Other Land-Use Parameters*

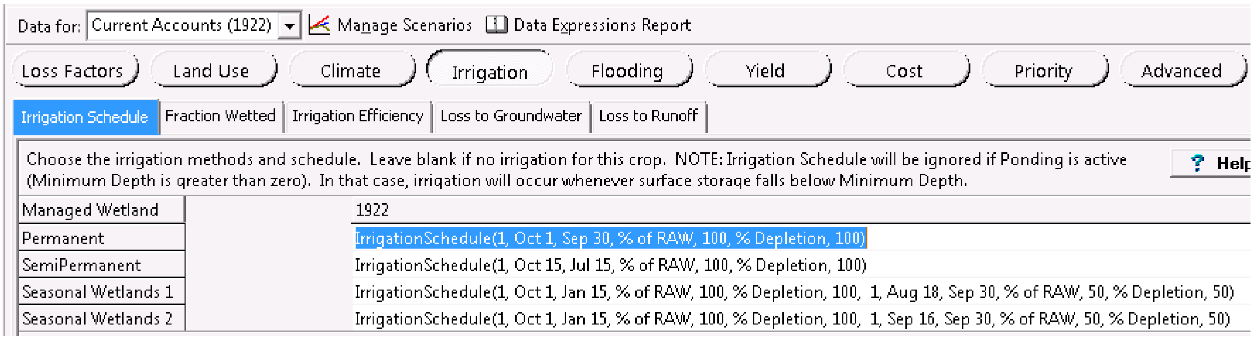
Other land-use parameters (*Surface Layer Thickness, Total Soil Thickness, Soil Water Capacity, Maximum Infiltration Rate, Effective Precipitation, Direct Recharge to GW, Initial Bucket 1 Depletion,* and *Initial Bucket 2 Depletion*) follow the same parameterization rules as indicated for agricultural and urban catchments. Refer to Section 4.4 for details.

4.5.3 Climate

All climate parameters follow the same parameterization rules as indicated for agricultural and urban catchments. Refer to Section 4.4 for details.

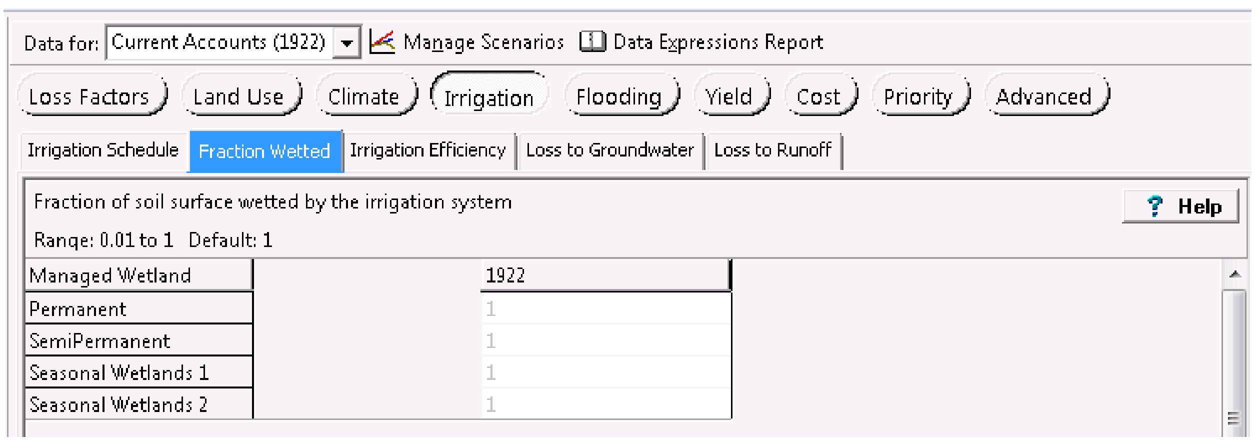
4.5.4 Irrigation

4.5.4.1 *Irrigation Schedule*



For wetlands, the irrigation schedule was set to be in effect during the flooding period. The irrigation trigger and irrigation amount parameters were given values of 30% of RAW and 100% of Depletion, however these values are meaningless as WEAP orders the irrigation necessary to maintain the Target Depth of ponding.

4.5.4.2 *Fraction Wetted*



This value is meaningless since the land is flooded. It was given the default value of 1.0.

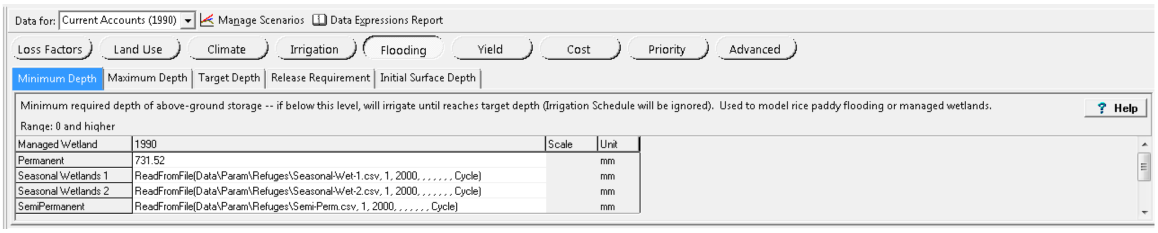
4.5.4.3 *Other Irrigation Parameters*

Other Irrigation Parameters include *Irrigation Efficiency*, *Loss to Groundwater*, and *Loss to Runoff*. These three parameters were given values of 100%, 0%, and 0% (WEAP default values) based on the assumption that there are no losses (other than the simulated deep percolation and evaporation) of water in the management of ponded wetlands.

4.5.5 Flooding

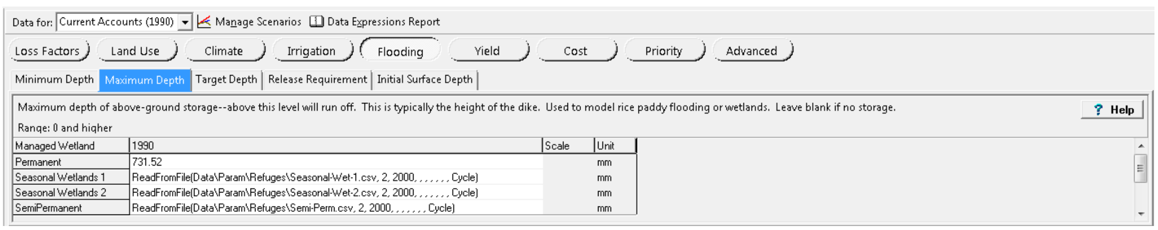
Flooded refuge lands were assumed to belong to one of four classes: permanent, semi-permanent, seasonal 1, or seasonal 2. The permanent wetlands have a constant depth of 30 inches (762 mm). The semi-permanent wetlands have a flooding schedule that starts October 15 and increases to 12 inches (300 mm) by October 31. This depth is maintained until July 31. Seasonal wetlands 1 are flooded from zero on September 1 to 12 inches (300 mm) on November 18. That depth is maintained until January 15. Seasonal wetlands 2 begins flood up on October 1 and reaches a depth of 12 inches (300 mm) by November 25. That depth is maintained until January 15.

4.5.5.1 *Minimum Depth*



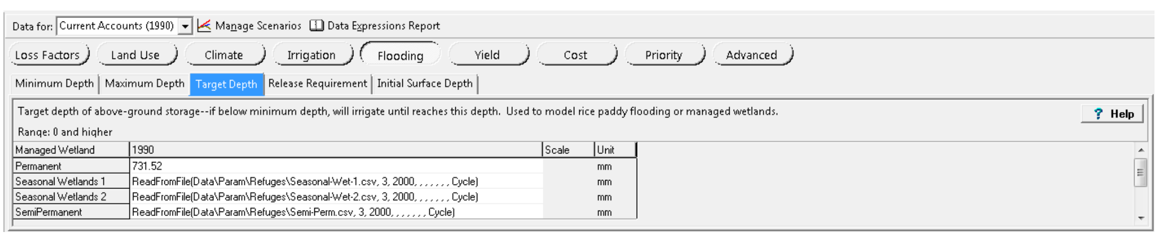
The minimum depth is specified using the timeseries described above.

4.5.5.2 *Maximum Depth*



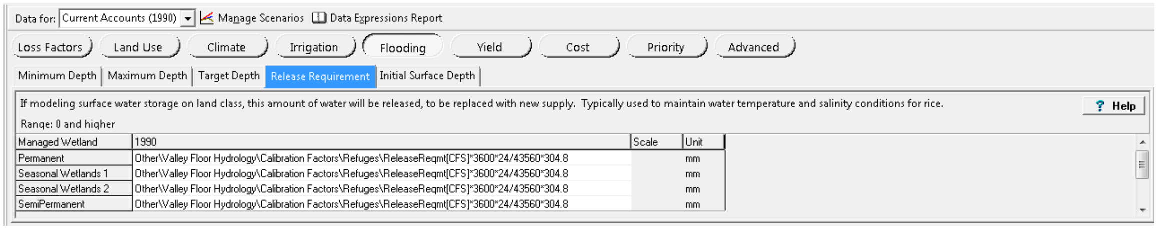
The maximum depth is specified using the timeseries described above with the exception that the maximum depth is held constant for an additional month in the winter to allow the seasonal wetlands to drain through infiltration and evaporation.

4.5.5.3 *Target Depth*



The target depth is specified using the timeseries described above.

4.5.5.4 *Release Requirement*



The release requirement for all flooded wetlands was set to 3 mm/d to simulate the flow through that managers utilize to maintain water quality.

4.5.5.5 *Initial Surface Depth*

This parameter was set to 476 mm for the permanent wetlands and 75 mm for the Seasonal Wetland 1. These are the only two wetland types that need a non-zero flood depth at the beginning of the water year (October 1).

4.5.6 Yield

The WEAP *Yield* feature for refuge catchments is not used.

4.5.7 Cost

The WEAP *Cost* feature for refuge catchments is not used.

4.5.8 Priority

4.5.9 Advanced

Use of the MABIA method is specified here, which follows the same parameterization rules as indicated for agricultural catchments. Refer to Section 4.4.7 for details.

4.6 Urban Catchment Parameters

Each urban area is represented by two nodes: a demand site (red) and a catchment (green). Urban catchments can be distinguished from their demand site counterparts by their "_O" suffix. For more on this distinction, see Urban Lands in Section 4.1.2.2. The urban catchment node in SacWAM contains parameters including Loss Factors, Land Use Climate, and Ponding. Refer to Table 4-16 for the location information of data associated with these parameters.

4.6.1 Loss Factors

The urban catchments simulate the rainfall runoff processes of the urban area. They do not simulate irrigation. Irrigation of urban landscapes is represented by the outdoor water in the urban demand sites. For that reason, the loss factors are generally not applicable to the urban catchments.

4.6.1.1 *Minimum Groundwater Pumping Factor*

For a complete discussion, see the corresponding Minimum Groundwater Pumping Factor sub-section in the Agricultural Catchments Section (4.4.2.6). For urban DUs, the factor is equal to 0.0, except for DUs U_02_SU, U_03_SU, U_26_NU2, and U_26_PU5, with factors of 0.3, 0.3, 0.2, and 0.5, respectively.

4.6.2 Land Use

4.6.2.1 *Area*

The following are the data sources used to determine **urban land use** data for SacWAM DUs:

- Important Farmland maps (Department of Conservation, 2006)
- County land use surveys undertaken by DWR's DSIWM, formerly Division of Planning and Local Assistance (DWR, 1994a-b, 1995a-b, 1996, 1997b, 1998a-c, 1999a-b, 2000a)

Since urban catchments are used to simulate runoff for DUs, land use acreages for these areas were needed. Land use in urban areas is divided among two land use classes: UR and NV. These land classes were aggregated from DWR Land Use Classifications for urban (Table 4-13) and native vegetation lands (Table 4-14).

Table 4-13. DWR Land Use Classifications Included in SacWAM Urban Land Use Classes

Category	Code	Description
Semi-agricultural	S1	Farmsteads
	S2	Livestock Feed Lots
	S3	Dairies
	S4	Poultry Farms
Urban	U	Not Classified
Urban Commercial	UC	Not Classified
	UC1	Offices, Retailers
	UC2	Hotels
	UC3	Motels
	UC4	Recreation Vehicle Parking, Camping
	UC5	Institutions
	UC6	Schools
	UC7	Municipal Auditoriums, Stadiums, Theaters
	UC8	Misc. High Water Use
Urban Industrial	UI	Not Classified
	UI1	Manufacturing, Assembling and Processing
	UI2	Extractive Industries
	UI3	Storage and Distribution
	UI6	Saw Mills
	UI7	Oil Refineries
	UI8	Paper Mills
	UI9	Meat Packing Plants
	UI10	Steel and Aluminum Mills
	UI11	Fruit and Vegetable Canneries
	UI12	Misc. High Water Use
	UI13	Sewage Treatment Plant/Ponds
	UI14	Waste Accumulation Sites
	UI15	Wind/Solar Farms
Urban Landscape	UL	Not Classified
	UL1	Lawn Area (irrigated)
	UL2	Golf Course (irrigated)
	UL3	Ornamental Landscape (irrigated)
	UL4	Cemeteries (irrigated)
	UL5	Cemeteries (not irrigated)
Urban Residential	UR	Not Classified
	UR1	Single Family (1-5 acres)
	UR2	Single Family (1-8 units/acre)
	UR3	Multi Family
	UR4	Trailer Courts
	UR11	Single Family (1-5 acres), <25% irrigated
	UR13	Single Family (1-5 acres), 51%-75% irrigated
Urban Vacant	UV	Not Classified
	UV1	Unpaved Areas
	UV3	Railroad Right-Of-Way
	UV4	Paved Areas
	UV6	Airport Runways

Table 4-14. DWR Land Use Classifications Included in SacWAM Native Vegetation Land Use Classes

Code	Description
NR4	Seasonal Duck Marsh
N45	Permanent Duck Marsh
E	Entry Denied
I	Idle
I1	Land not cropped in current or previous season, but cropped in past 3 years
I2	New lands being prepared for crop production
NB	Barren Land
NB1	Dry Stream Channel
NB2	Mine Tailing
NB3	Native Barren
NC	Native Classes Unsegregated
NR	Riparian Vegetation
NR1	Marsh
NR2	High Water Table Meadow
NR3	Trees and Shrubs
NS	Not Surveyed
NV	Native Vegetation
NV1	Grass
NV2	Light Brush
NV3	Medium Brush
NV4	Heavy Brush
NV5	Brush and Timber
NV6	Forest
NW	Water Surface

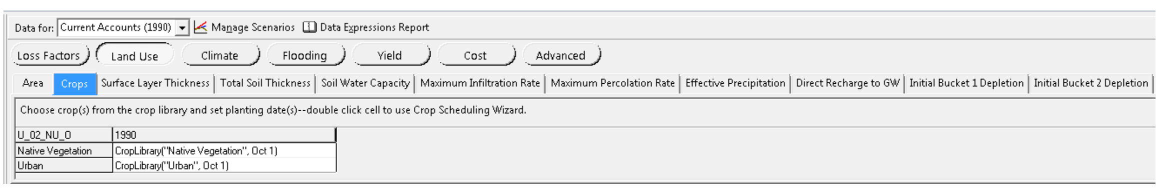
ICA of DAUs from water years 1998-2007 was obtained from the DSIWM. The average annual ICA for this 10-year period was assumed to be representative of "existing conditions." Then a survey of land use for the Central Valley was assembled from county land use surveys to create a continuous mosaic in GIS, although the land use data are derived from different years. The GIS mosaic was intersected with DU polygons and with DAU polygons to obtain the historical irrigated land area for each DU and for each DAU. These historical values were converted to a value representing existing conditions by scaling the historical land use data to match the 10-year DAU value. The following example illustrates this process:

1. Assume the 10-year historical average for wheat in DAU X=10,000 acres
2. Assume the GIS data from the land use mosaic shows 8,000 acres of wheat in DAU X
3. Assume the GIS data from the land use mosaic shows 500 acres of wheat in DU A
4. If DU A is located within DAU X, the existing level acreage for wheat=500*(10,000/8,000) acres

In instances in which irrigated land exists inside municipal boundaries (which are represented by an urban DU), the irrigated land was 'removed' from the urban DU and associated with a neighboring agricultural DU. For example, assume there exist 4,000 acres of irrigated land in U_02_NU and 6,000 acres of irrigated land in neighboring agricultural DU A_02_NA. The 4,000 acres of irrigated land were removed from U_02_NU and associated with A_02_NA. Consequently, there are 10,000 total acres of irrigated land represented by agricultural DU A_02_NA. The total areas of each DU (A_02_NA and U_02_NU) were preserved by adjusting the amount of native vegetation adjusted. In the example above, 4,000 acres of native vegetation lands would be added to DU U_02_NU and 6,000 acres of native vegetation lands would be subtracted from A_02_NA.

Although there is an “urban” land use classification within the ICA-DSIWM dataset, Important Farmland maps (Department of Conservation, 2006) were used instead as they provide updated information on urban land areas. Important Farmland maps are provided by county from the Farmland Mapping and Monitoring Program. To create these maps, current land use information is combined with NRCS soil survey data (NRCS, 2013b). Land use type for the Important Farmland dataset was determined using current and historical aerial imagery coupled with field verification. Aerial image sources include the US Department of Agriculture National Agricultural Imagery Program, AirPhotoUSA, the High Altitude Missions Branch of the National Aeronautics and Space Administration (NASA), USGS’ Earth Resources Observation and Science (EROS) Center, and SPOT Data Corporation (Department of Conservation, 2006). Lands are grouped into the following classes: Prime Farmland, Farmland of Statewide Importance, Unique Farmland, Farmland of Local Importance, Grazing Land, Urban and Built-Up Land, Other Land, and Water. Acreages from Department of Conservation classes “Urban and Built-Up Land” were used to represent the SacWAM urban land class (UR). Since these data were presented on the county level, these acreages were intersected with a county-DAU layer and a DU layer to determine the urban acreages at the DAU and DU level. Because these acreages were used instead of the ICA-DSIWM dataset, an adjustment had to be made to preserve the total area of the DUs. Consequently, an adjustment was made for native vegetation acreage to offset the increase or decrease in urban acreage within a single DU.

4.6.2.2 *Crops*



Native Vegetation and Urban classes were added to the **crop library** (General>Crop Library), just as agricultural crops were. Since these “crop types” have no planting date, these “crops” were given a planting date of October 1 (the start of the water year) and a season length of 365 days.

4.6.2.3 *Maximum Percolation Rate*

A *Maximum Percolation Rate* was not set for the urban class of urban catchments; it was set at 1000 for the native vegetation class under *Other Assumptions\Valley Floor Hydrology\Calibration Factors\MaxPercRate_NV*.

4.6.2.4 *Other Land-Use Parameters*

Other land-use parameters (*Surface Layer Thickness, Total Soil Thickness, Soil Water Capacity, Maximum Infiltration Rate, Effective Precipitation, Direct Recharge to GW, Initial Bucket 1 Depletion,* and *Initial Bucket 2 Depletion*) follow the same parameterization rules as indicated for agricultural catchments. Refer to Section 4.4 for details.

4.6.3 Climate

All climate parameters (*Precipitation, ETref, Min Temperature, Max Temperature, Latitude, Min Humidity, Average Humidity, Max Humidity, Wind, Wind speed measurement height, Altitude, Solar Radiation, Sunshine Hours, Cloudiness Fraction,* and *Krs*) follow the same parameterization rules as indicated for agricultural catchments. Refer to Climate in Section 4.4 for details.

4.6.4 Flooding

Flooding does not apply to urban catchments. Therefore all parameters remain as their WEAP default value (*Initial Surface Depth*, *Minimum Depth, Maximum Depth, Target Depth,* and *Release Requirement* all have values of 0 mm).

4.6.5 Yield

The WEAP 'Yield' feature for urban catchments is not used.

4.6.6 Cost

The WEAP 'Cost' feature for urban catchments is not used.

4.6.7 Advanced

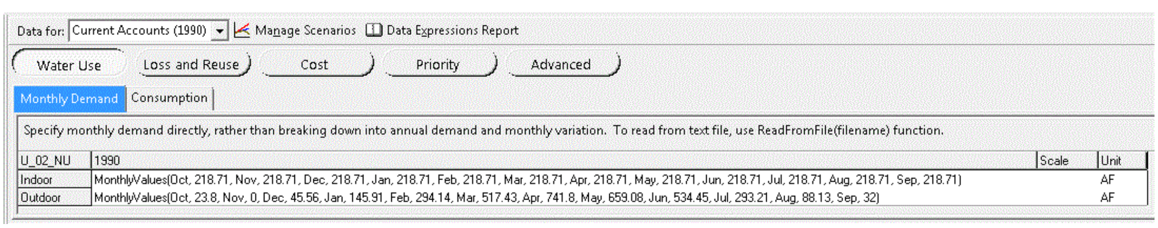
Use of the MABIA method is specified here, which follows the same parameterization rules as indicated for agricultural catchments. Refer to Advanced in Section 4.4 for details.

4.7 Urban Demand Site Parameters

Urban demand sites contain data on monthly indoor and outdoor use of piped water for urban DUs. They can be distinguished from urban catchments by their lack of "_O" at the end of their label. Rainfall runoff processes related to urban land are simulated in the urban catchment objects. Location information for urban demand site data is provided in Table 4-16.

4.7.1 Water Use

4.7.1.1 *Monthly Demand*



Monthly Demand was specified for Indoor (D_I) and Outdoor (D_O) use in SacWAM and are given in acre-feet. The following are the data sources used to determine monthly water demands for urban areas:

DSIWM datasets are summarized in the California Water Plan (Bulletin 160-09 series), and in periodic urban water use (Bulletin 166 series) and industrial water use reports (Bulletin 124 series) (DWR, 1982, 1994d). Water use data from years 1998 to 2003 (DWR, 2011) include:

- population by DAU,
- percentage water use by customer class (residential, manufacturing, commercial, industrial, large landscape),
- indoor-outdoor split for residential and commercial sectors,
- source of water (groundwater or surface water), and
- per capita water use (DWR Northern Regional Office).

Urban Water Management Plans

California municipal suppliers providing service to more than 3,000 customers or supplying more than 3,000 acre-feet of water per year are required to prepare and follow an UWMP. These plans are submitted to DWR every five years, and are summarized by DSIWM as part of the California Water Plan. Suppliers report and evaluate their water deliveries and uses, water supply sources, efficient water uses, and demand management measures. These plans also include information on base daily per capita water use, urban water use targets, interim urban water use targets, and compliance daily per capita water use. UWMPs aim to help municipal suppliers develop long-term conservation plans.

Water Forum Agreement

The Water Forum Agreement helps manage water supply for regions next to the lower American River, and specifically applies to water purveyors within WBAs 26N and 26S (Water Forum, 2006). The goal of this agreement is to balance providing a safe and reliable water supply with maintaining ecological and recreational habitat.

National Census Data

The US Census Bureau collects information via a mailed questionnaire every 10 years. Questions regard income, ethnicity and housing. Geospatial population data are then given on the block-level and larger geographical units. These data are available online at www.census.gov.

Urban demands were determined mostly using Public Water System Statistics (PWSS) questionnaires and 2010 Census data, with some information provided from UWMPs and the integrated groundwater–surface water model developed for Placer, Sacramento, and San Joaquin Counties. Calculation of urban demands relied on the same process as that used in DSIWM. The only exception is that the data provided by DSIWM were originally at the county or DAU scale, and then aggregated at the DU level in SacWAM.

DSIWM collects water use and population data through PWSS questionnaires that are mailed annually to public water purveyors. The data collected from the purveyors in these questionnaires include water production data, population data, metered water deliveries (if applicable), and active service connections by customer class. The six customer classes are: Single-Family Residential, Multi-Family Residential, Residential, Commercial, Industrial, and Landscape, and Other. The “Other” class includes a variety of uses, such as system flushing and wholesale water sold. These data exist through calendar year 2010.

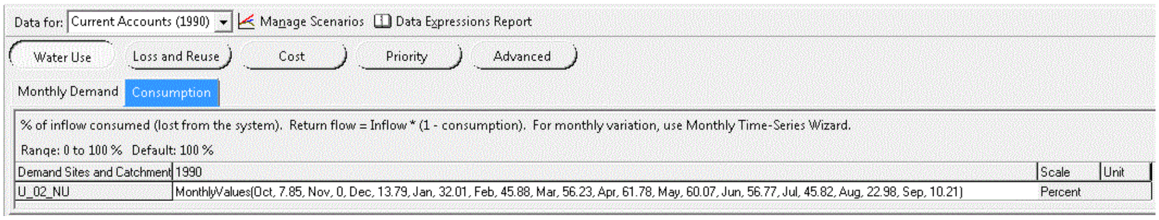
PWSS publicly served water purveyor production data are used to determine urban water demands in SacWAM. The assumption made in using this dataset is that water demands are equal to water production data. Total urban water demand is the sum of production data for public and self-supplied users, but only publicly supplied production data are given in PWSS questionnaires. Publicly supplied and self-supplied production data were combined to determine urban water demands on the county or DAU scale. These data were then aggregated at the urban DU level for use in SacWAM. For each DU, a list of water purveyors, the population served by that purveyor, and water production data are given. To determine the population that is self-supplied rather than publicly supplied, the population served by public water suppliers was subtracted from the total population within a WBA. The total population within a WBA was determined from 2010 National Census data. This calculation assumes that the population located outside public WA service areas is self-supplied by groundwater. Water use for the self-supplied population was determined by calculating the product of the population and per capita water use. Data on per capita water use was determined in a dataset supplied by DWR's Northern Regional Office. SacWAM population estimates were determined from DSIWM data for 2010, and were defined by DU in the following way:

- GIS data layers of county and DAU boundaries are intersected with 1990 and 2000 census block data to estimate populations for these years.
- California Department of Finance estimates define city (incorporated) and unincorporated populations for counties following year 2000.
- Unincorporated population defined by the California Department of Finance is disaggregated into county-DAUs based on growth rates for unincorporated populations from 1990 to 2000.

SacWAM uses monthly urban demands, so annual DSIWM data had to be disaggregated before being input into SacWAM. Monthly urban demands were based on historical production data for water years 2006 to 2010 from PWSS. In some cases, no delivery data were available for cities within a SacWAM DU, so the monthly delivery pattern is assumed to be the same as that of an adjacent DU. Within the urban demand site node, SacWAM separates urban demand sites into two classes: indoor and outdoor demands. SacWAM defines the monthly indoor demand as equivalent to the demand of the lowest month, and assumes that the indoor demand is constant throughout the year. The outdoor demand class for each month is defined as the difference between that month's total demand and the indoor demand. For example, the minimum demand month for "U_02_NU" is February, with a demand of 218.71 acre feet, so the indoor demand is 218.71 acre feet for each month of the year. In March, the total demand is 264.27 acre feet, so the outdoor demand for March is 45.56 acre feet (264.27-218.71=45.56 acre feet). Urban demand data are input into WEAP as a monthly timeseries. The **urban demand** includes all processing steps relating to the *Monthly Demand* data input into SacWAM.

There are SacWAM regions where no PWSS data exist. In these cases, *Monthly Demand* data were taken from the 2010 UWMPs, and aggregated on the DU level. For regions in SacWAM WBAs 26S and 26N, water purveyor data assembled by Boyle Engineering in the Integrated Groundwater Surface Water Model were used.

4.7.1.2 Consumption



Consumption is defined as the percentage of inflow that is consumed (lost from the system). **Urban consumption** monthly demands are explicitly divided into indoor and outdoor water use, so the percentage of consumed water must include a weighted average of these two demands. Indoor consumption is assumed to be zero percent, meaning that there is no loss from the system. SacWAM assumes that 80% of water for outdoor use is consumed (through landscape ET). The following equation is used to calculate monthly consumption for urban demand sites:

$$\textit{Consumption (\%)}=\frac{(0*D_I+0.8*D_O)}{(D_I+D_O)}$$

where: D_O= Outdoor Monthly Demand (as defined above in Monthly Demand, Section 4.7.1.1)

For urban demand sites that discharge to surface water bodies, such as to the Sacramento Regional WWTP, the assumption that indoor consumption is zero percent and outdoor consumption is 80 percent is tested during calibration. Historical flows from WWTPs were obtained from the California Data Exchange Center (CDEC), and used to compare to model outputs. Where outflows do not match historical data, the *Loss to Groundwater* parameter was adjusted.

4.7.2 Loss and Reuse

4.7.2.1 Loss Rate

The *Loss Rate* is assumed to be equal to 0.

4.7.2.2 Reuse Rate

The *Reuse Rate* is assumed to be equal to 0.

4.7.3 Cost

The WEAP *Cost* feature for urban demand sites is not used.

4.7.4 Priority

Demand priorities are discueed in Section 7.2.4.

4.7.5 Advanced

Use method for specifying water use is “monthly demand.”

4.8 Other Demand Site Parameters

4.8.1 South of Delta Demands

Water demands located south of the Delta and served by the DMC and California Aqueduct were included in the model to correctly represent the simulation of Delta exports. Demands for water from the DMC and California Aqueduct were divided into agricultural, exchange, urban, and refuge demands (Table 4-15). Additional "demands" were developed to represent losses. All values were derived from DWR's **Bulletin 113** and **CVP Contractor data**.

Table 4-15. Demand Nodes Used to Represent CVP and SWP South of Delta Demands

State Water Project	Central Valley Project
SWP South Bay Aqueduct Losses	CVP Upper DMC Ag Demands
SWP Upper CA Demands	CVP Upper DMC Urban Demands
SWP CA Demands North	CVP Upper DMC Losses
SWP CA Losses R1 to R2	CVP Upper DMC Water Rights
SWP San Luis Canal Losses R3 to R7	CVP Lower DMC Ag Demands
SWP CA Losses South R8C to R18A	CVP Lower DMC Refuge Demands
SWP South Coast Losses R17 to R30	CVP Lower DMC Exchange Demands
SWP CA Demands South	CVP Lower DMC Losses
SWP Demands South Coast	CVP San Felipe Ag Demands
Cross Valley Canal	CVP San Felipe Urban Demands
	CVP San Luis Canal Ag Demands
	CVP San Luis Canal Urban Demands
	CVP San Luis Canal Refuge Demands
	CVP San Luis Canal Losses R3 to R7
	CVP Mendota Pool Ag Demands
	CVP Mendota Pool Refuge Demands
	CVP Mendota Pool Exchange Demands
	CVP Mendota Pool Water Rights Demands
	CVP CA Refuges

Key: CA=California Aqueduct; CVP=Central Valley Project; DMC=Delta-Mendota Canal; SWP=State Water Project.

4.8.1.1 *Water Use*

Annual Activity Level

The WEAP *Annual Activity Level* feature for other demand sites is not used.

Annual Water Use Rate and Monthly Varaition

Monthly demands for south-of-Delta CVP and SWP contractors are set equal to the product of the annual full contract amount and percent monthly variation. For the CVP, this variation is based on recent historical deliveries.

Monthly Demand

Monthly demands for south-of-Delta SWP contractors are specified by month. These demands are dynamically calculated based on the Table A amount and the monthly pattern of requests, which is a function of the SWP allocation.

Consumption

All deliveries to CVP and SWP south-of-Delta contractotrs is assumed to be 100 percent consumed, as all return flows exit the model domain.

4.8.1.2 *El Dorado ID*

Demands served by the Sly Park project are represented with the El Dorado ID demand site. Demand data were derived from historical flows through the **Camino Conduit**.

4.9 Data Directory

Table 4-16 provides location information in the 2014_WB_WEAP data directory for the datasets referenced in Chapter 4.

Table 4-16. File Location Information for Valley Floor Demand Sites and Catchments

Referenced Name	File Name	File Location*
agricultural land use	SACVAL_Ag_LU_Area.xlsx	Agricultural_Catchments\Land_Use
Bulletin 113	132-12_Table1-6.pdf and 132-12_TableB-4.pdf	South of Delta Demand Sites
Camino Conduit	Camino Conduit Demand Calculation.xlsx	Other Demand Sites
crop library	Crop Library.xlsx	Agricultural_Catchments\Land_Use
CVP Contractor Data	CVP_Water_Contractors_2015.pdf	South of Delta Demand Sites
Daily CIMIS RH Analysis	Daily CIMIS RH Analysis.xlsm	Climate\Valley Floor
delta land use	SACVAL_Ag_Delta_LU_Area.xlsx	Agricultural_Catchments\Land_Use
effective precipitation	Effective Precipitation.xlsx	Agricultural_Catchments\Land_Use
ET calibration	ET Calibration.xlsx	Agricultural_Catchments\Land_Use
evaporative loss	SACVAL_Evaporative_Loss.xlsx	Agricultural_Catchments\Loss_Factors
fraction wetted	SACVAL_FractionWetted.xlsx	Agricultural_Catchments\Irrigation
groundwater pumping	SACVAL_Minimum_Goundwater_Pumping.xlsx	Agricultural_Catchments\Loss_Factors
irrigation efficiency	SACVAL_Irrigation_Efficiency.xlsx	Agricultural_Catchments\Irrigation
lateral flow	SACVAL_Lateral_Flow.xlsx	Agricultural_Catchments\Loss_Factors
latitudes	catchment_and_DU_latitudes.xlsx	...
Livneh grid	Livneh_Grid_Coords_UTM11.shp	GIS\Climate
loss to groundwater	SACVAL_Loss_to_Groundwater.xlsx	Agricultural_Catchments\Irrigation
loss to runoff	SACVAL_Loss_to_Runoff.xlsx	Agricultural_Catchments\Irrigation
operational spills	SACVAL_Operational_Spill.xlsx	Agricultural_Catchments\Loss_Factors
potential application efficiencies	*Individual files by Water Budget Area*	Agricultural_Catchments\Loss_Factors\PAE
rainfall runoff calibration	Rainfall Runoff Calibration.xlsb	Other_Assumptions\Valley Floor Hydrology\SCS Curve Number
refuge land use	SACVAL_Refuge_LU_Area.xlsx	Refuge_Catchments\Land_Use
reuse	SACVAL_Reuse.xlsx	Agricultural_Catchments\Loss_Factors
rice management description	Hillaire_2000.pdf	References
seepage loss	SACVAL_Seepage_Loss.xlsx	Agricultural_Catchments\Loss_Factors
surface soils	Central Valley Soil Analysis.xlsm	Agricultural_Catchments\Land_Use
tailwater	SACVAL_Tailwater.xlsx	Agricultural_Catchments\Loss_Factors
urban consumption	SACVAL_Urban_WU_Consumption.xlsx	Urban_Demand_Sites\Water_Use
urban demand	SACVAL_Urban_WU_MonthlyDemands.xlsx	Urban_Demand_Sites\Water_Use
urban land use	SACVAL_Urban_LU_Area.xlsx	Urban_Catchments
valley floor processor	Valley_Floor_Livneh_Data_Processor.xlsm	Climate\Valley Floor
water budget areas	water_budget_areas.shp	GIS\Boundaries
WEAP Input Data	*Individual files by catchment*	Climate\WEAP Input Data

*Files located at Data\Demand_Sites_and_Catchments\... except for Rainfall Runoff Calibration (Data\...), Rice Management Description (References\...), and GIS files (GIS\...).

3

Chapter 5 Demand Sites and Catchments – Upper Watersheds

The portion of the watersheds above the valley floor boundary are referred to as the upper watersheds and serve as the main supply of water for Sacramento Valley water users. In SacWAM, the flows from these watersheds are simulated using one of two user-selected approaches. The first is the use of input flow timeseries developed by DWR. These flows are input into SacWAM as headflows on fictitious streams that have the same name as the DWR inflow timeseries. These inflows are listed in Table 6-1 and described in Section 6.1.1.

The second approach to generating upper watershed flows is the use of the catchment object. In SacWAM, these objects have been set to use the Soil Moisture Model. This model is described in Yates, Sieber et al. (2005) and in the WEAP help file (Calculation Algorithms - Evapotranspiration, Runoff, Infiltration and Irrigation - Soil Moisture Method). These catchment objects provide a representation of rainfall-runoff processes including snow accumulation and melt, infiltration, surface runoff, ET, interflow, deep percolation, and baseflow. By adding a hydrological model of the upper watersheds to SacWAM, the inflow boundary of the model shifts from specified inflows to meteorological inputs (precipitation, temperature, wind speed, and humidity) across the upper watersheds. Using this approach permits analysis based on climate model outputs or synthetic meteorology. The creation of these catchment objects was based on work done in earlier modeling efforts including Young et al. (2009); Yates, Purkey et al. (2009); Mehta et al. (2011); and Joyce et al. (2011).

The documentation that follows describes the spatial analysis required to parameterize the catchment objects, the water management infrastructure, the operations rules for the water management infrastructure, and the calibration of the model to natural and managed flows.

5.1 Delineation of Upper Watersheds

Several spatial analysis steps were necessary to prepare geographic data for import to WEAP. First, watersheds were subdivided into subwatersheds based on the location of points of interest where the model needs to simulate flows. Typically this is at dams and stream gauges. Second, each subwatershed was subdivided into elevation bands and a single catchment was created to represent the land area within each elevation band. This was done in order to properly represent the variation in climate that is a function of elevation. Third, each elevation band, in each subwatershed, was sub-divided into different land cover classifications. Within the catchment object, all hydrological calculations are performed for each of these individual land cover classes. A more detailed description of these three steps is provided below.

5.1.1 Selection of Pour Points

Pour points were created at the locations of dams and USGS stream gauges as specified by SWRCB (Table 5-1).

Table 5-1. Attributes of the Pour Points Used in the Model

Watershed	Name	Latitude	Longitude	WEAP_Name
American R	Folsom Lake inflows*	38.71148	-121.15087	P508_American_01
	NF American R at NF Dam*	38.93748	-121.02316	P508_American_02
	MF American R above confluence with NF*	38.91493	-121.02540	P508_American_03
	SF American R nr Placerville*	38.77157	-120.81303	P508_American_04
	Union Valley Reservoir	38.86606	-120.44081	P508_American_05
	Ice House Reservoir	38.82355	-120.36155	P508_American_06
	Loon Lake	38.98761	-120.33170	P508_American_07
	French Meadows Reservoir	39.11095	-120.47017	P508_American_08
	Hell Hole Reservoir	39.05784	-120.41276	P508_American_09
Antelope Ck	Antelope Ck nr Red Bluff*	40.20007	-122.12251	P504_Antelope_01
Battle Ck	Battle Ck nr Cottonwood*	40.39810	-122.14651	P504_Battle_01
Bear R	Camp Far West Reservoir local inflows	39.05017	-121.31463	P508_Bear_01
	Lake Combie	39.01382	-121.04178	P508_Bear_02
	Rollins Reservoir	39.13581	-120.95260	P508_Bear_03
Big Chico Ck	Big Chico Ck nr Chico*	39.77542	-121.75341	P504_BigChico_01
Butte Ck	Butte Ck*	39.72636	-121.70803	P504_Butte_01
Cache Ck	Cache Ck above Rumsey local inflows	38.91024	-122.27961	P505_Cache_01
	Clear Lake inflow*	38.92520	-122.61398	P505_Cache_02
	Indian Valley inflow*	39.08058	-122.53654	P505_Cache_03
Calaveras R	Calaveras R at DU boundary	38.07331	-120.92668	P604_Calaveras_01
	New Hogan inflow	38.15053	-120.81357	P604_Calaveras_02
Clear Ck	Clear Ck at DU boundary*	40.51581	-122.52535	P502_Clear_01
	Whiskeytown Reservoir	40.59941	-122.53941	P502_Clear_02
Cosumnes R	Cosumnes R*	38.50861	-121.04417	P604_Cosumnes_01
	Jenkinson Lake	38.71679	-120.56931	P604_Cosumnes_02
	Camp Ck Diversion Tunnel	38.72466	-120.52505	P604_Cosumnes_03
Cottonwood Ck	NF and MF Cottonwood Ck nr Olinda*	40.38445	-122.47645	P502_Cottonwood_01
	SF Cottonwood Ck nr Olinda*	40.32576	-122.44505	P502_Cottonwood_02
Cow Ck	Sum of Cow Cks	40.55511	-122.23131	P504_Cow_01
Deer Ck	Deer Ck nr Vina*	40.01387	-121.94729	P504_Deer_01
Delta	Los Vaqueros Reservoir	37.83713	-121.72798	P601_Delta_01
Dry Ck of the Yuba R	Merle Collins Reservoir inflows*	39.32244	-121.31348	P508_DryofYuba_01
Elder Ck	Elder Ck nr Paskenta*	40.02442	-122.51086	P502_Elder_01
Feather R	Lake Oroville inflow	39.54301	-121.49225	P508_Feather_01
	Ponderosa Dam inflow*	39.54927	-121.30327	P508_Feather_02
	Little Grass Valley Reservoir*	39.72521	-121.02006	P508_Feather_05
	NF Feather R at Pulga*	39.79436	-121.45166	P508_Feather_07
	Lake Almanor Inflows*	40.17377	-121.08589	P508_Feather_08
	MF Feather R nr Merrimac*	39.70817	-121.27079	P508_Feather_09
	Sly Ck Reservoir inflows	39.58238	-121.11566	P508_Feather_04
	Miocene Diversion Dam	39.81391	-121.57109	P508_Feather_03
	Hendricks Diversion Dam*	39.93811	-121.53220	P508_Feather_06
Jackson Ck	Amador Reservoir Inflow	38.30356	-120.88944	P604_Jackson_01
Little Chico Ck	Little Chico Ck	39.73349	-121.77160	P504_LittleChico_01
Littlejohns Ck	Littlejohns d/s of Rock Ck confluence	37.91374	-120.96217	P603_Littlejohns_01
Marsh Ck	Marsh Ck*	37.89338	-121.72128	P601_Marsh_01
Mill Ck	Mill Ck nr Los Molinos*	40.05457	-122.02413	P504_Mill_01
Mokelumne R	Dry Ck d/s of Sutter Ck	38.35954	-120.98954	P604_Dry_01
	Camanche Reservoir inflow*	38.22614	-121.02190	P604_Mokelumne_01
	Pardee Reservoir inflow*	38.25710	-120.85037	P604_Mokelumne_02
	Mokelumne R nr Mokelumne Hill*	38.31264	-120.72019	P604_Mokelumne_03
Pit R	Pit R nr Montgomery Ck*	40.84323	-122.01625	P501_Pit_01
	Muck Valley-Clarks Valley watershed boundary	40.96967	-121.16871	P501_Pit_02
	Goose Lake-Upper Pit watershed boundary	41.69688	-120.40137	P501_Pit_03
Putah Ck	Lake Berryessa inflows*	38.51344	-122.10464	P505_Putah_01

Table 5-1. Attributes of the Pour Points Used in the Model cont.

Watershed	Name	Latitude	Longitude	WEAP_Name
Sacramento R	McCloud R above Shasta Lake*	40.95824	-122.21972	P501_McCloud_01
	Shasta Lake inflows*	40.71830	-122.41856	P501_Sacramento_01
	Sacramento R at Delta*	40.93955	-122.41427	P501_Sacramento_02
	Paynes and Sevenmile Cks*	40.26344	-122.18707	P504_Sacramento_96
Stony Ck	Stony Ck below Black Butte Dam nr Orland*	39.81828	-122.32429	P502_Stony_01
	Stony Gorge Reservoir local inflows*	39.58579	-122.53271	P502_Stony_02
	East Park Reservoir inflow*	39.36184	-122.51640	P502_Stony_03
Thomes Ck	Thomes Ck at Paskenta*	39.88704	-122.52778	P502_Thomes_01
Trinity R	Lewiston Lake local inflows	40.72723	-122.79306	P102_Trinity_01
	Trinity Reservoir (Claire Engle Lake) inflows	40.80100	-122.76271	P102_Trinity_02
Yuba R	Deer Ck inflow to Yuba R*	39.22447	-121.26853	P508_Yuba_01
	Englebright Reservoir local inflows*	39.23992	-121.26904	P508_Yuba_02
	New Bullard Bar Reservoir	39.39320	-121.14244	P508_Yuba_03
	Scott's Flat Reservoir	39.27266	-120.93077	P508_Yuba_04
	Oregon Ck below Log Cabin Dam nr Camptonville*	39.43944	-121.05806	P508_Yuba_05
	Middle Yuba R below Our House Dam*	39.41167	-120.99694	P508_Yuba_06
	Slate Ck below Div Dam nr Strawberry*	39.61556	-121.05167	P508_Yuba_07
	North Yuba R below Goodyears Bar*	39.52528	-120.93750	P508_Yuba_08
	Bowman Lake	39.44902	-120.65271	P508_Yuba_09
	Lake Spaulding	39.32730	-120.64337	P508_Yuba_10
	Jackson Meadows Reservoir	39.50865	-120.55639	P508_Yuba_11
	Fordyce Lake	39.37978	-120.49638	P508_Yuba_12

Key: Ck=Creek; Div=Diversion; MF=Middle Fork; NF=North Fork; nr=near; R=River; SF=South Fork.
* Indicates there is a USGS gauge associated with the pour point.

NHDPlus **flow accumulation** rasters were used to ensure pour points were located on streams. The NatGeo basemap (available in ESRI's ArcGIS) was used to guide pour-point placement at dam inflows. Stream gauge locations were based on the coordinates and descriptions available in USGS Water Data reports (available here: http://wdr.water.usgs.gov).

5.1.2 Delineation of Subwatersheds

A **pour point grid** was created from the pour points shapefile using the Snap Pour Points tool and the **flow accumulation** raster as the input accumulation raster, with a snap distance of 5 m.

Subwatersheds were delineated using the pour point grid and NHDPlus **flow direction grids** for regions 18b and 18c, using the *Watershed* tool, and resulting in **upper watershed rasters**.

The *Raster-to-Polygon* tool was used to convert the watershed rasters to features, which were then unioned and clipped to the DU boundary. Gaps were disallowed so that polygons would be created for any spaces between watersheds stemming from minor discrepancies between the pour-point delineated watersheds and the HUC-12 boundaries (e.g. around the closed basins). Closed basins that fell within the 1801, 1802, and 1804 HUC-4s were added to upper watersheds based on HUC-8 and HUC-10 divisions.

A layer was created of the gaps between the watersheds and the DU boundary by making a dummy layer that encompassed all of the area that potentially held gaps, clipping this to the DU and then erasing from it the upper watersheds layer with an xy tolerance of 0 (automatically converted to two times the resolution). The gaps layer was merged with the upper watersheds and features that had not been assigned to a pour point (i.e. the gap features) were selected and multi-part features exploded.

Gap features >10km^2 were assigned a pour point value of "Uncaptured: River Name," where River Name is the stream/river into which the area drains. These areas are not captured by the gauge on their respective streams. In the two cases that a gap area drained into more than one river and each drainage area was greater than 10km^2, the gap areas were divided along HUC-12 boundaries, and the resulting uncaptured areas assigned to their respective rivers.

The remaining gap features—those <10km^2—were again selected and the Eliminate tool was run to join these sliver polygons with the neighboring polygon with which they shared the longest border. The Eliminate tool was run twice to get rid of all the slivers, resulting in a final **upper watersheds** layer (Figure 5-1).

A field was added to the upper watersheds layer—WEAP_sws. This was populated by PXXX_river_XX where PXXX was already established and the XX suffix was chosen so that 01 was located at the basin outlet and the highest numbers represented the headwaters.

5.1.3 Elevation Bands

Elevation data are NHDPlus' **NEDsnapshot** reclassified (Table 5-2), using the default setting of "double precision" to produce a **reclassified elevation grid**.

Table 5-2. Reclassification of Elevation Data

Original values (centimeters)	New value (meters)
-2180–50,000	500
50,000–100,000	1,000
100,000–150,000	1,500
150,000–200,000	2,000
200,000–250,000	2,500
250,000–300,000	3,000
300,000–350,000	3,500
350,000–400,000	4,000
400,000–450,000	4,500
No Data	No Data

The Raster-to-Polygon tool was used to convert these grids to shapefiles, simplify polygons left unchecked, and the shapefiles were merged and clipped to the upper watersheds to produce a **reclassified elevation shapefile**.[8]

[8] In order to prepare the NED 18b and 18c regions for merging, a buffer was erased from the outside edge of 18b to reduce discrepancies between the datasets where they overlapped. This was accomplished by dissolving 18b, creating a -10km buffer around it, and erasing the buffered footprint from the 18c polygon layer. The clipped 18c and buffered 18b were unioned with gaps disallowed and dissolved to achieve one feature per elevation band.

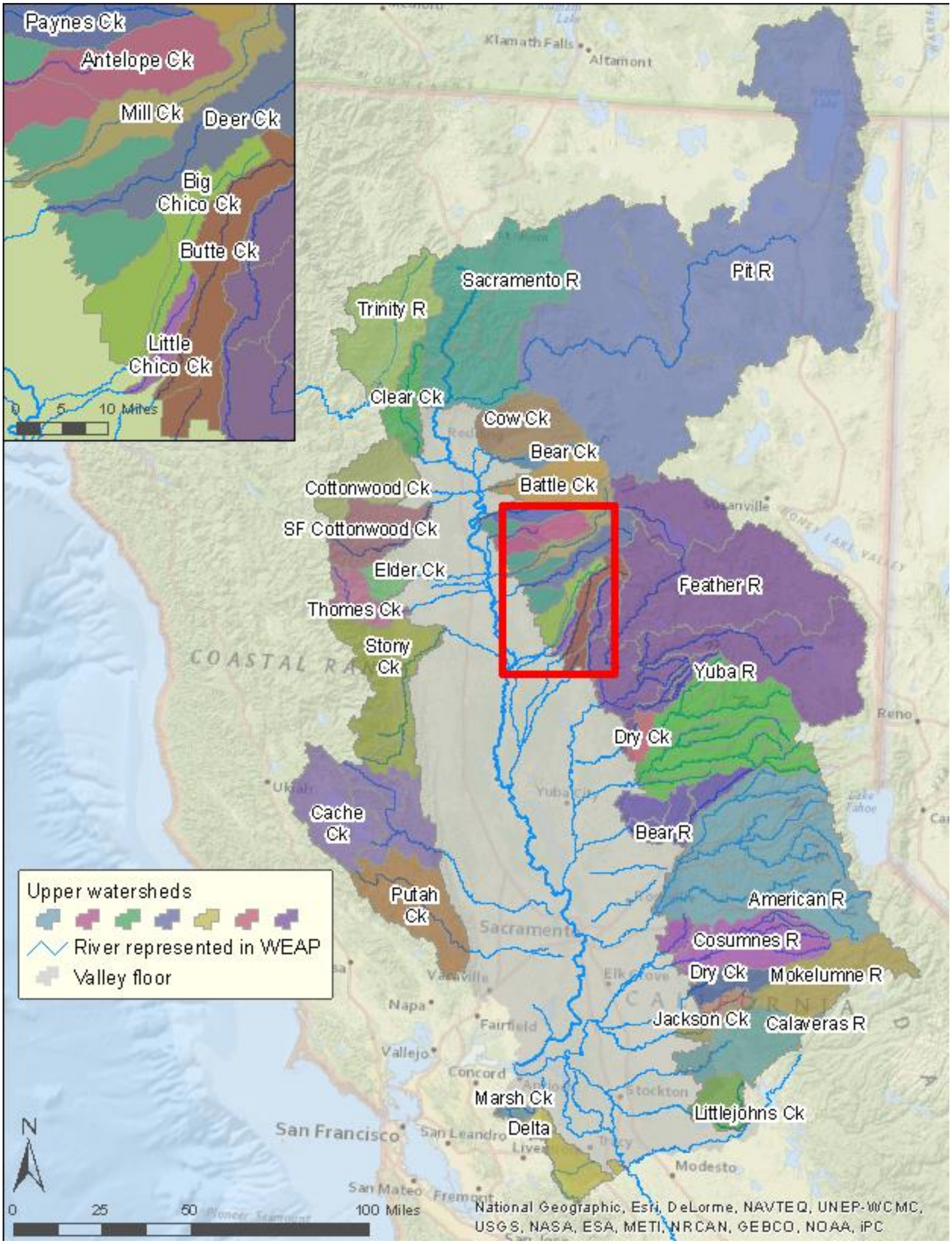


Figure 5-1. Upper Watersheds

Red rectangle delineates zoomed in inset area.

5.1.4 Creation of WEAP Catchments

Upper watersheds and the **reclassified elevation shapefile** were intersected to form **catchments**. Nine elevation bands split the 92 subwatersheds of the 34 watersheds into 351 catchments. The attribute table for catchments, including areas for each polygon, was exported from ArcGIS into a **catchment analysis** file. A pivot table was used to calculate relative area in each elevation band within a subwatershed. When an extreme elevation band (highest or lowest band in the subwatershed) occupied less than 15.5% of the total area of a subwatershed, this elevation band was lumped with the adjacent elevation band in the same subwatershed. If the sum of the areas of these combined elevation bands was still less than 15.5%, it was lumped with the next adjacent elevation band in the same subwatershed. Through this process, the number of catchments for use in WEAP was reduced to 194 (Table 5-3).

Table 5-3. WEAP Catchments

Watershed	Subwatersheds	Catchments
American	9	22
Antelope	2	5
Battle	1	3
Bear	1	2
Bear	4	6
BigChico	2	4
Butte	2	5
Cache	3	6
Calaveras	3	4
Clear	2	4
Cosumnes	4	7
Cottonwood	2	6
Cow	1	3
Deer	1	3
Delta	2	3
Dry	1	2
DryofYuba	1	2
Elder	1	4
Feather	10	21
Jackson	2	3
LittleChico	1	2
Littlejohns	1	1
Marsh	1	2
McCloud	1	3
Mill	1	3
Mokelumne	3	6
Paynes	1	2
Pit	3	6
Putah	1	2
Sacramento (P501)	2	5
Sacramento (P504)	4	7
Stony	4	9
Thomes	1	3
Trinity	2	5
Yuba	12	23
Total	**92**	**194**

To facilitate calibration and analysis, the model was divided into seven regions (Table 5-4).One subwatershed is included in two regions because of a transfer between regions.

Table 5-4. Model Regions

Model Region	Subwatersheds
Shasta	Clear, McCloud, Pit, Sacramento (01, 02), Trinity
Westside	Cache, Cottonwood, Elder, Putah, Stony, Thomes
Northeast Streams (NEStreams)	Antelope, Battle, Bear, Big Chico, Butte, Cow, Deer, Feather (06),* Little Chico, Mill, Paynes, Sacramento (96, 97, 98, 99)
Feather	Feather, Dry of Yuba
CABY	Cosumnes (all but 99), American, Bear, Yuba
Eastside	Calaveras, Cosumnes (99), Dry, Jackson, Littlejohns, Mokelumne
Delta	Delta, Marsh

*The Feather_06 subwatershed was included in both the Northeast Streams and Feather regions in order to model a trans-basin transfer.

Zonal statistics were performed to produce tables of the average elevation of each catchment, using the **reclassified elevation shapefiles**. The tables were joined to the **catchments** shapefile, and the average elevation data added.

5.1.5 Land Cover

Land cover data are National Land Cover Database (NLCD) 2011. Most NLCD classes correspond to a single WEAP class, with the exception of low-, medium-, and high-intensity developed land. Low-intensity developed land is subdivided in WEAP to include a residential landscape class so that the user can control the portion of residential lots that is pervious, thus allowing for a more accurate simulation of runoff from these areas. Similarly, portions of medium- and high-intensity area are designated as commercial-industrial landscape. Proportions of low-, medium-, and high intensity developed land are stored in *Other\Urban Outdoor\SAC\Area Factors*.

The NLCD 2011 raster for the coterminous United States was clipped to the Sacramento Basin with a 100 m buffer with “Maintain Clipping Extent” unchecked to disallow resampling. This was output to a **land-use tif**. Raster-to-Polygon converted the tif to a polygon layer, which was then clipped to the upper watersheds extent, with “simplify polygons” unchecked. WEAP level 1 and 2 fields were added to facilitate calculation of areas for the land-use classes used as input in WEAP (Table 5-5).

The catchment-NLCD intersections were dissolved on the WEAP1 and catchment fields, resulting in one polygon per catchment–land use combination in seven **simplified NLCD** files. Land use areas by catchment were exported and used in Excel lookup tables to produce area formulas (for low-, medium-, and high intensity urban; and residential and commercial/industrial landscape) and raw areas (for all other land use categories) for import into WEAP in square miles. Areas were rounded to three decimal places; this resulted in “0” values for land uses that covered less than approximately 1300m^2. This data processing can be reviewed in the **catchment land use** file.

Table 5-5. National Land Cover Database Land Use Classes and Corresponding WEAP Classes

Gridcode	NLCD 2006	WEAP 1	WEAP_2
21	Developed, Open Space	OpenSpace	Urban
22	Developed, Low Intensity	Low Int Res Landscape*	
23	Developed, Medium Intensity	Med Int	
		CommInd Landscape*	
24	Developed, High Intensity	Hi Int	
82	Cultivated Crops	Cultivated	Irrigated
81	Pasture/Hay	Pasture	
12	Perennial Ice/Snow	Barren	Non Irrigated
31	Barren Land		
41	Deciduous Forest	Forest	
42	Evergreen Forest		
43	Mixed Forest		
11	Open Water	Open Water	
52	Shrub/Scrub	Non Forest	
71	Grassland/Herbaceous		
90	Woody Wetlands		
95	Emergent Herbaceous Wetlands		

*Commercial/Industrial Landscape and Residential Landscape are calculated as percentages of Low-, Medium-, and High Intensity Developed and are not assigned to specific pixels in the data files.

5.2 Upper Watershed Parameters

All values with the exception of Initial Z1 and Initial Z2 can be reviewed in the **upper watershed parameterization** file. During calibration of the upper watershed scaling factors were created to adjust hydraulic parameters on a sub watershed scale such that all parameters for catchments contributing to a specific calibration point have the same value. The mapping of these groupings of catchments to calibration points is provided in the **upper watershed expressions** file.

5.2.1 Climate

5.2.1.1 *Precipitation, Temperature, Humidity, Wind*

Similar to the approach taken for the valley floor catchments (described in Section 4.3), the Livneh et al. (2013) **climate dataset** was used to provide spatially interpolated *temperature*, *precipitation*, and *wind* inputs. The following steps were followed:

1. The **Livneh grid** was intersected with the **catchments**.
2. A VBA macro in **upper watershed processor** was used to calculate the area weighted average of the maximum and minimum daily temperature, precipitation, and wind speed for all **Livneh grid** cells that intersected each catchment. This differed from the approach taken on the valley floor. It was assumed that an area weighted average would give a more representative value of the climate data for each catchment since the catchments cover up to 500 m of elevation and there is a strong gradient in precipitation and temperature as a function of elevation. This dataset was converted into monthly average data since the upper watershed hydrological calculations are performed on a monthly time step.
3. An average monthly relative humidity data timeseries was derived from a long term climatological average at Blue Canyon and applied to all catchments.

4. Data from steps 2 and 3 were combined to create the **WEAP Input Data**.

The wind data in the Livneh et al. (2013) dataset are provided as wind speed at 10 m above the ground. This dataset was modified to represent wind speed at 2 m above the ground using the following relationship (Neitsch et al., 2005):

$$wind_2=wind_{10} * (2/10)^{0.2} \qquad \text{Equation 5-1}$$

where:

$wind_2$ is the wind speed at 2 m above the ground;
$wind_{10}$ is the wind speed at 10 m above the ground.

5.2.1.2 *Cloudiness Fraction*

No data were input for the *Cloudiness Fraction*. It was assumed that errors introduced by this assumption are minimal since there is little cloudiness during the period of highest ET (Apr – Oct).

5.2.1.3 *Latitude*

Centroids were calculated in ArcGIS for all catchments. Latitudes were calculated for these points in decimal degrees in WGS1984 UTM Zone 11 N. **Latitudes** were rounded to three decimal places and imported into WEAP.

5.2.1.4 *Freezing Point and Melting Point*

Freezing and melting points are regionally calibrated values. The regions are defined and further discussed in Section 7.4.1.1 of Chapter 7 on Other Assumptions.

5.2.1.5 *Albedo*

Default WEAP values were used for *Albedo Upper Bound* (0.25) and *Albedo Lower Bound* (0.15), No value was set for *Albedo*, resulting in WEAP calculating this value based on snow accumulation.

5.2.1.6 *Initial Snow*

No initial snow data were entered. The model runs begin with the assumption that no snow is on the ground.

5.2.1.7 *Snow Accumulation Gauge*

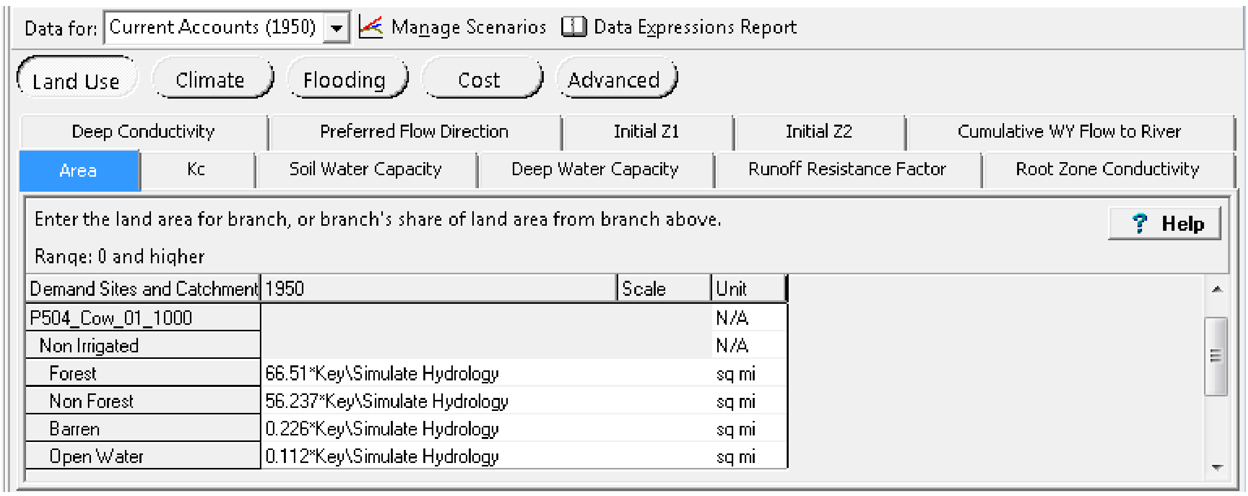
Snow water equivalent data were downloaded from DWR's CDEC (www.cdec.water.ca.gov). Snow gauge locations were spatially joined with the catchments layer so that the elevation of the snow gauge could be compared with the average elevation of the catchment it falls in. Only stations within 100 m of the average elevation of their respective catchment were considered. If more than one station met the elevation criterion, the one with more complete data was chosen to represent the catchment.

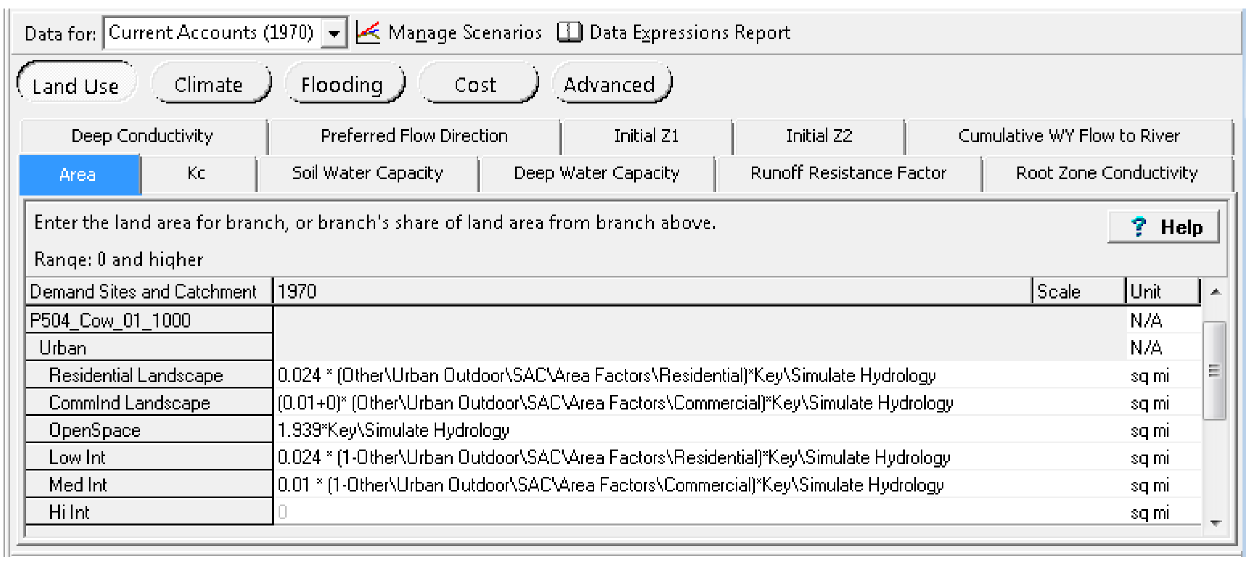
Adjusted snow equivalent data were used as available; raw data were used for dates lacking adjusted data. Data from a total of 26 snow gauges were entered. However, the data were not used during calibration as it was found the 500-meter elevation bands represent too large a range of elevation to have meaningful comparisons between observed and simulated snow accumulation.

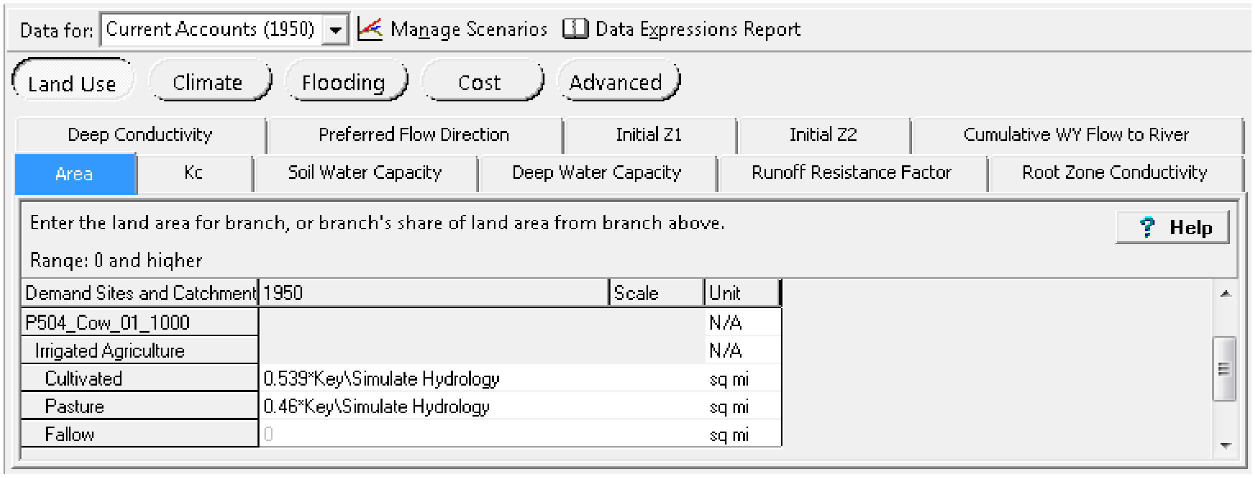
5.2.2 Land Use

5.2.2.1 *Area*

Land-use areas for upper watershed catchments were calculated based on the procedure outlined in Section 5.1.5. All area values from the GIS analysis can be found in **catchment land use**. Each area expression has the additional multiplier **Key\Simulate Hydrology* which sets the area value to zero if the DWR inflow timeseries are being used (see Section 9.4).

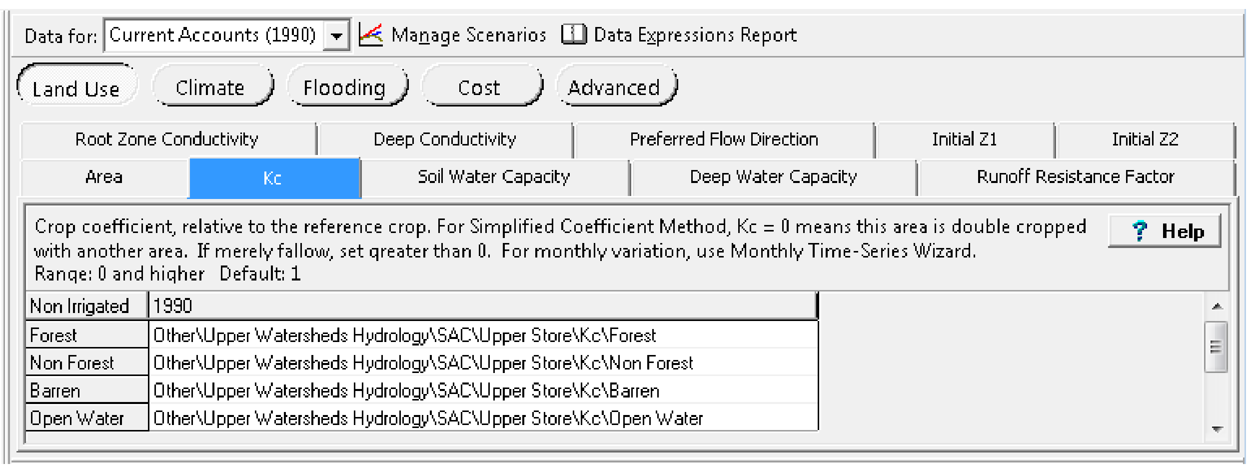


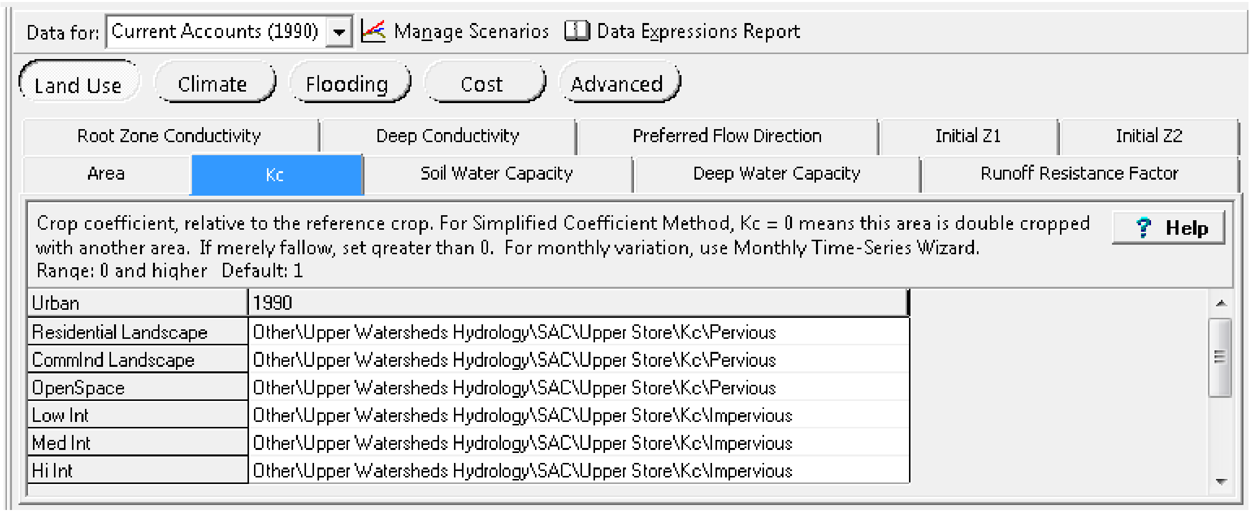


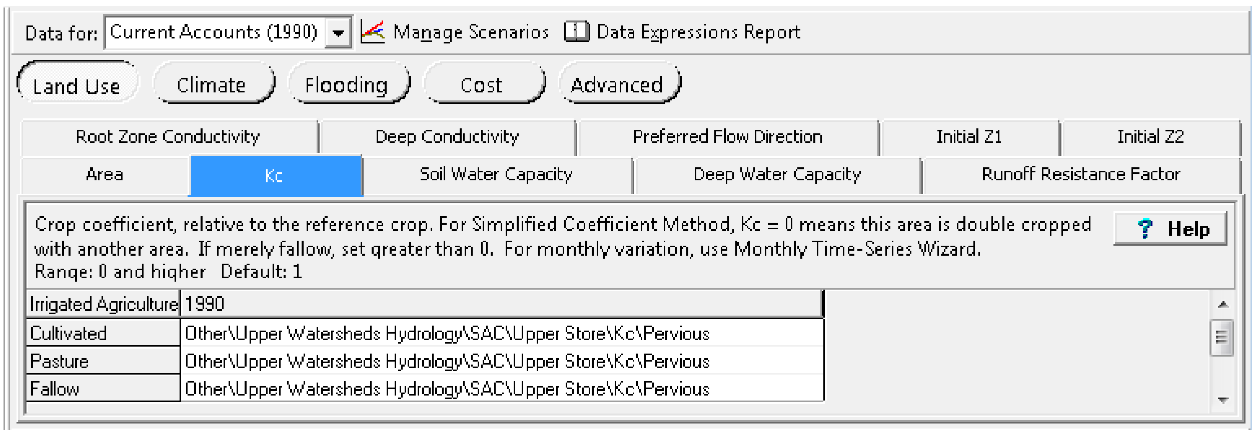


5.2.2.2 *Kc*

The crop coefficient (Kc) is used to scale the potential ET (ETo) calculated by WEAP to a level appropriate for the particular land cover type of interest. In SacWAM, land use–specific values from the CVPA model were used. These values range from 0.7 for impervious land classes to 1.2 for forested areas. In SacWAM, these values do not vary in time. See **upper watershed parameterization** and **upper watershed expressions** for details.

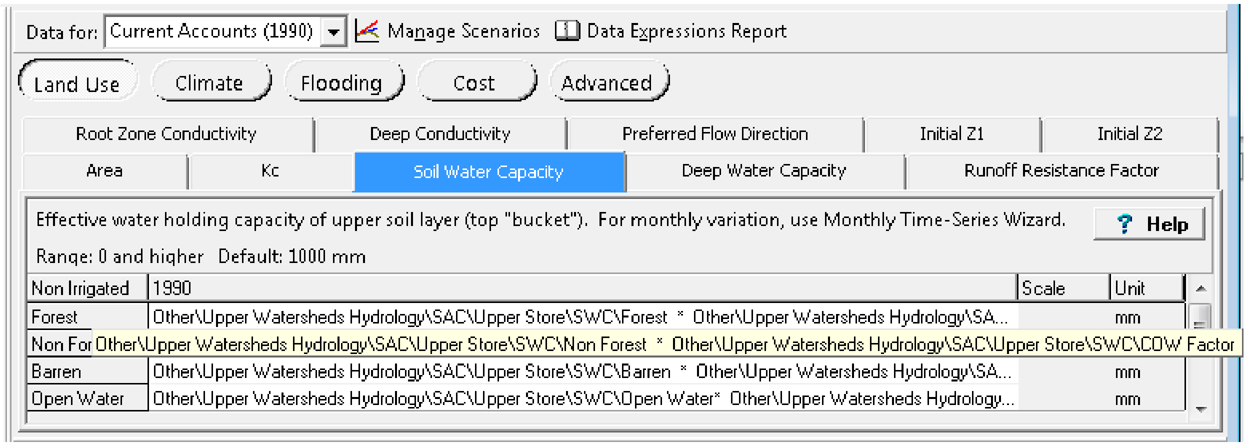


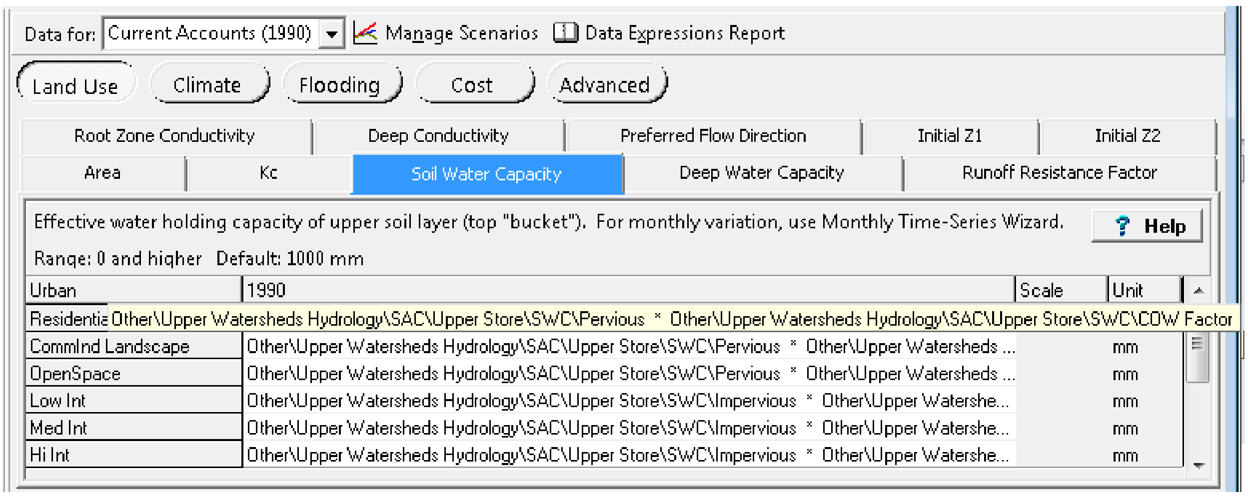


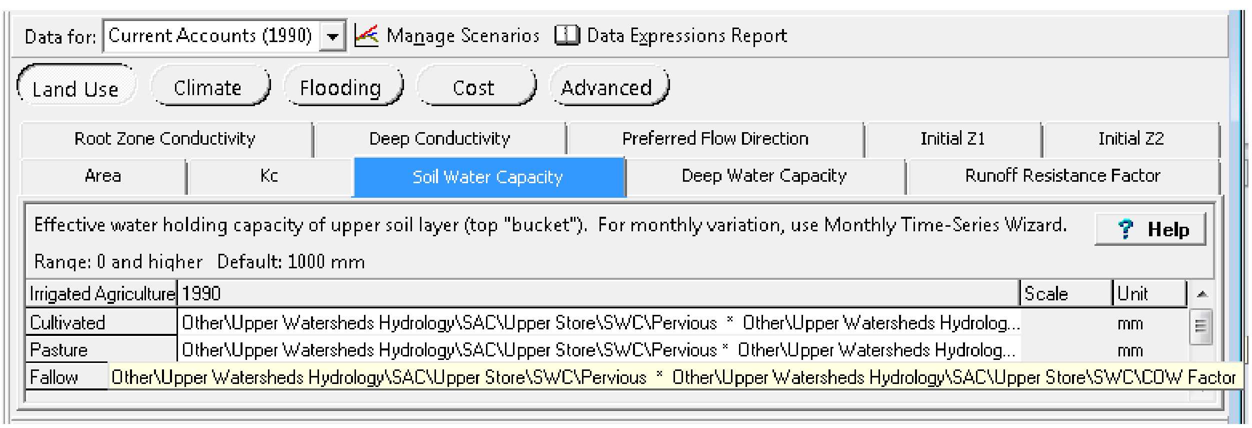


5.2.2.3 *Soil Water Capacity*

The soil water capacity is the maximum amount of water that can be stored in the upper compartment of the Soil Moisture Model. This is effectively the root zone soil water capacity. Soil water capacity was specified through two parameters—a land use–specific value multiplied by a subwatershed-specific multiplier. The land use–specific parameter was taken from the CVPA model. During calibration of SacWAM, subwatershed scaling factors were utilized to scale the soil water capacity values for all catchments that contribute to a specific flow calibration point. The scaling factors are located in *Other Assumptions\Upper Watershed Hydrology\SAC\Upper Store\SWC*. See **upper watershed parameterization** and **upper watershed expressions** for details.

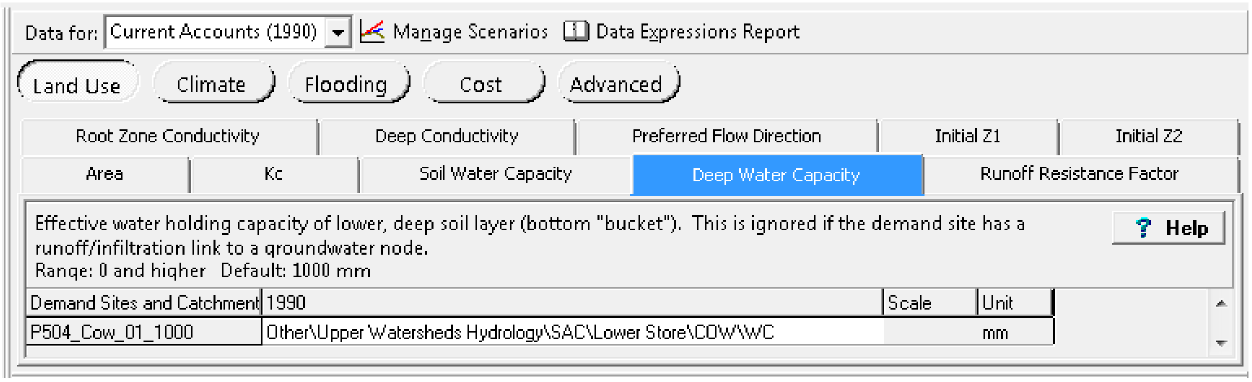






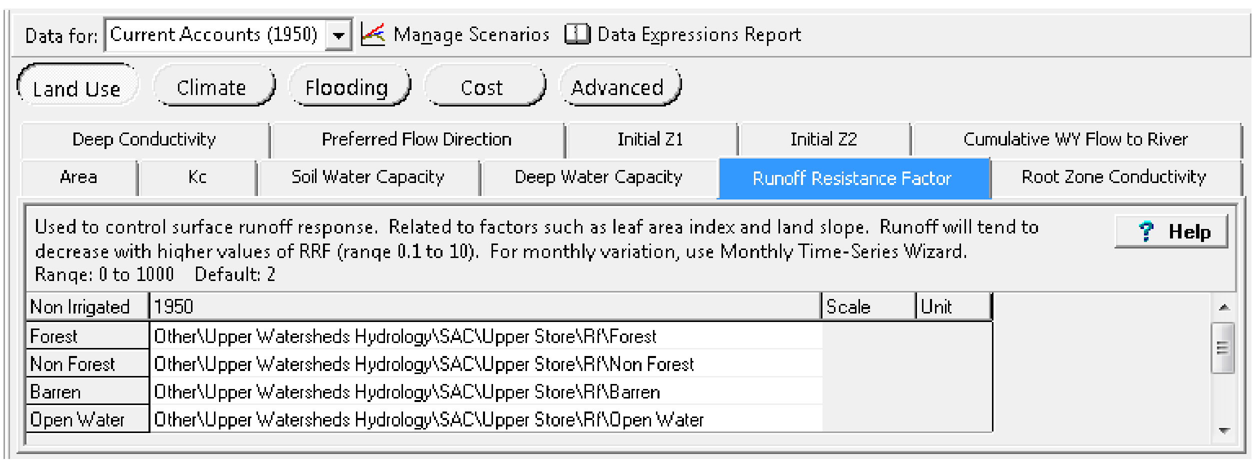
5.2.2.4 *Deep Water Capacity*

The deep water capacity is the maximum amount of water that can be stored in the second compartment of the Soil Moisture Model. Deep water capacity (WC) was initially given a value of 1000 mm for all catchments. During calibration of the baseflow portion of the hydrograph for some sub watersheds it was necessary to alter the value. These values are located in *Other Assumptions\Upper Watershed Hydrology\SAC\Lower Store* under the parameter name WC. All values are provided in **upper watershed parameterization**.



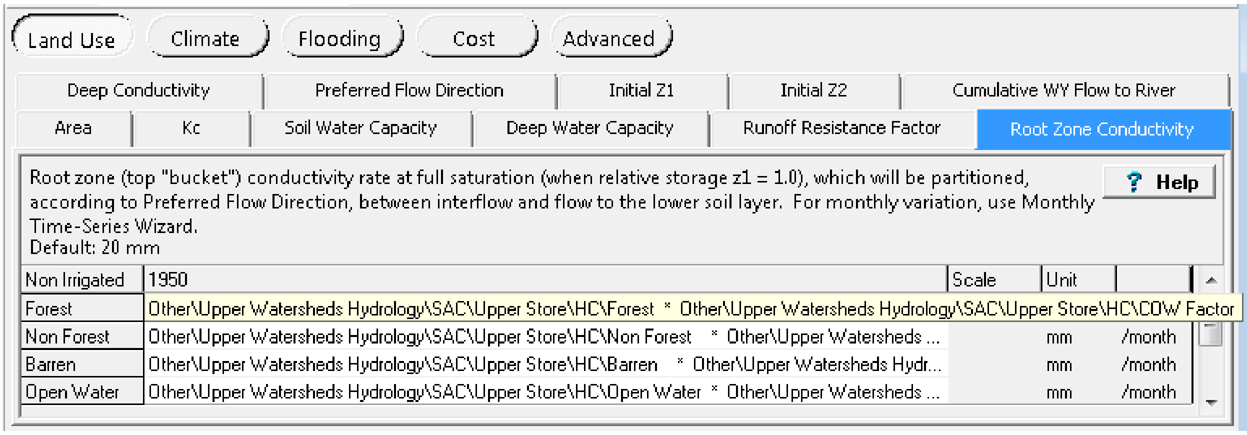
5.2.2.5 *Runoff Resistance Factor*

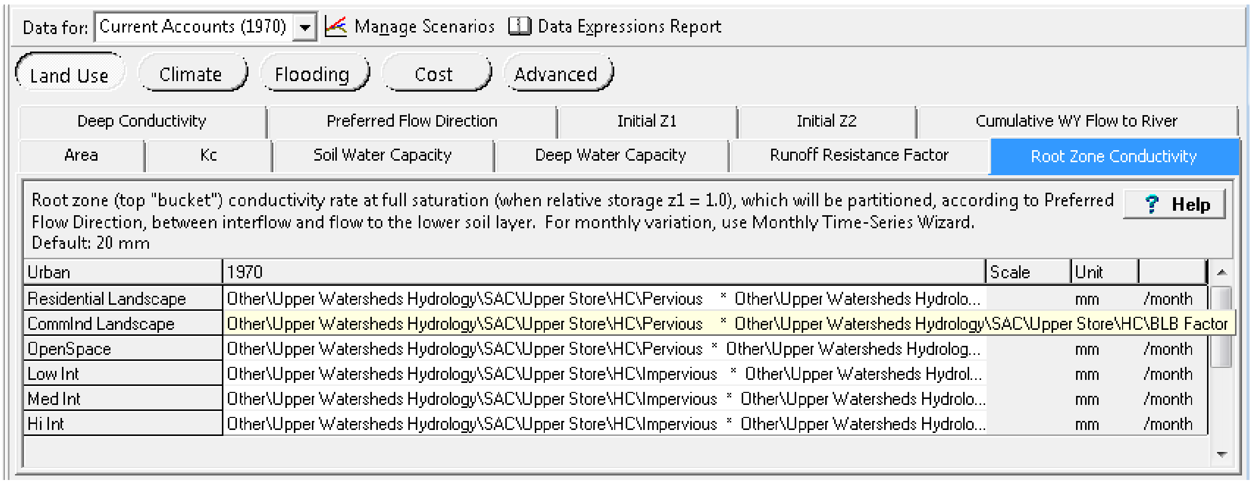
The runoff resistance factor reduces the rapidity of surface runoff thereby increasing the potential for water to infiltrate into the soil. In SacWAM, the runoff resistance factor (Rf) is based on land use class with smaller values for more pervious land cover types such as barren soil and impervious surfaces in urban areas. Higher values were assigned to areas with denser vegetation cover such as forests and pervious surfaces in urban areas. These values are located in *Other Assumptions\Upper Watershed Hydrology\SAC\Upper Store\Rf.* All values are provided in the **upper watershed parameterization** file.

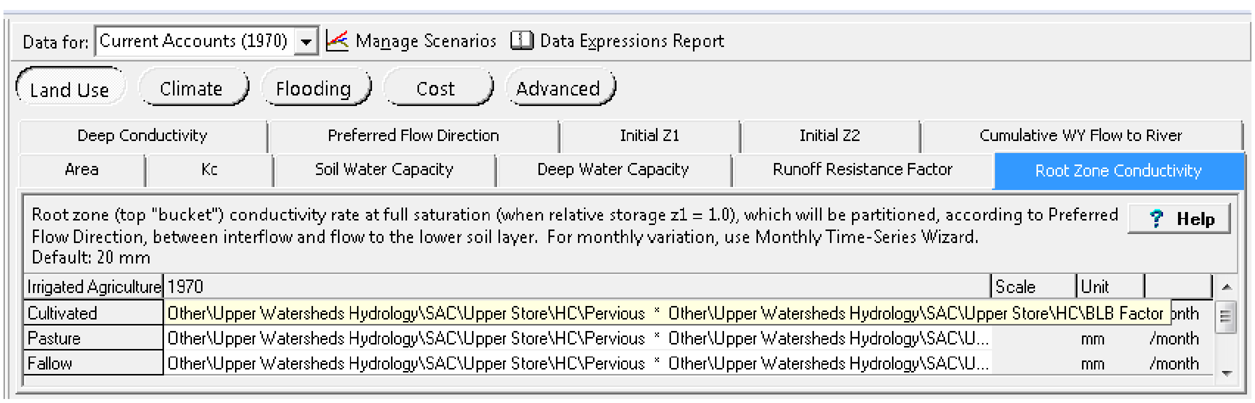


5.2.2.6 *Root Zone Conductivity*

The root zone conductivity specifies the hydraulic conductivity in the root zone. Root zone conductivity (HC) is specified through two parameters—a land use–specific value multiplied by a sub watershed-specific multiplier. The land use–specific parameters were obtained from the CVPA model. During calibration these values were modified on a subwatershed basis. These values are located in *Other Assumptions\Upper Watershed Hydrology\SAC\Upper Store\HC.* See **upper watershed parameterization** and **upper watershed expressions** for details.

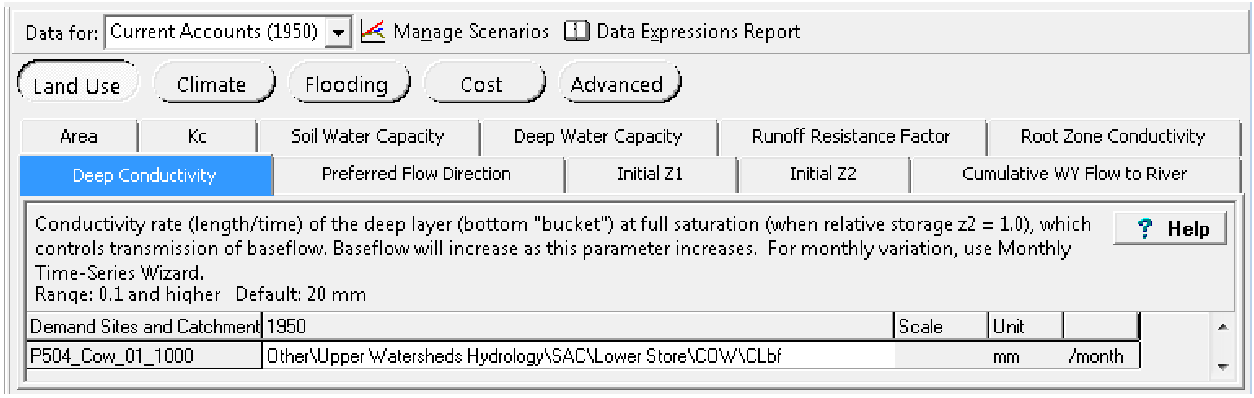






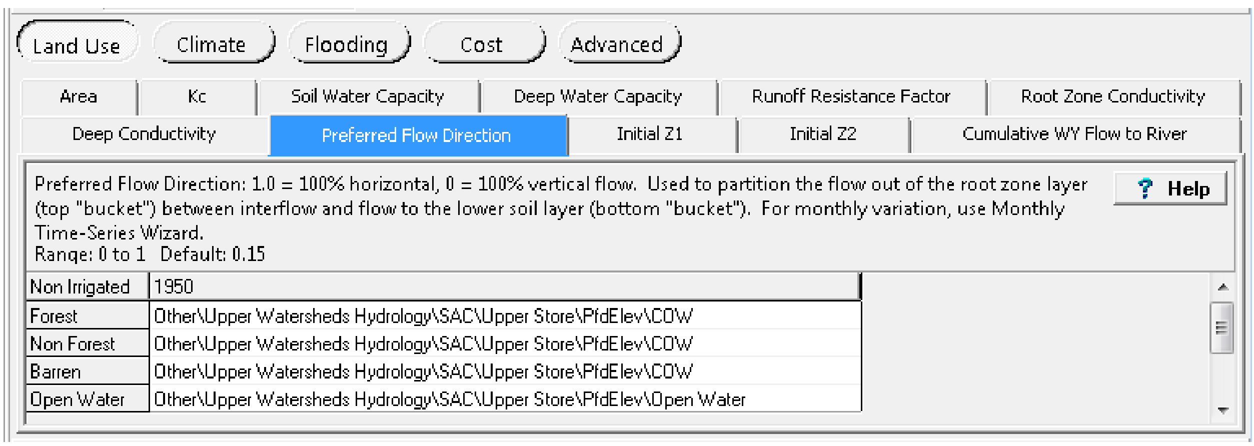
5.2.2.7 *Deep Conductivity*

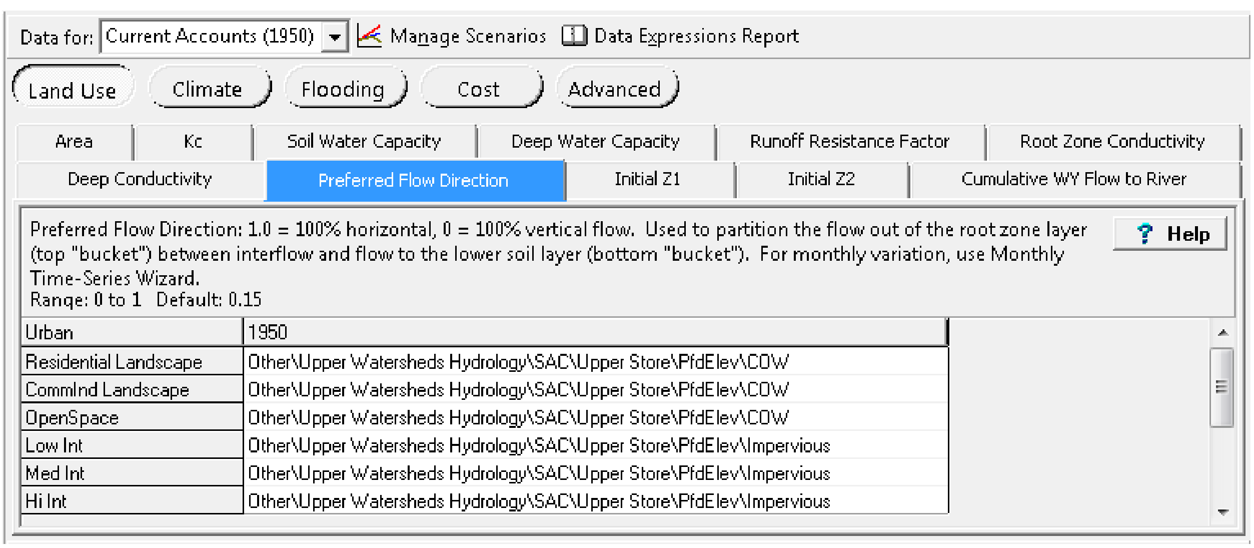
The deep conductivity parameter specifies the conductivity of the second, deep, compartment of the Soil Moisture Model. This parameter was initially set to a value of 500 mm/month, similar the CVPA. During calibration it was adjusted on a sub watershed basis. These values are located in *Other Assumptions\Upper Watershed Hydrology\SAC\Lower Store* under the parameter name CLbf. See **upper watershed parameterization** and **upper watershed expressions** for details.

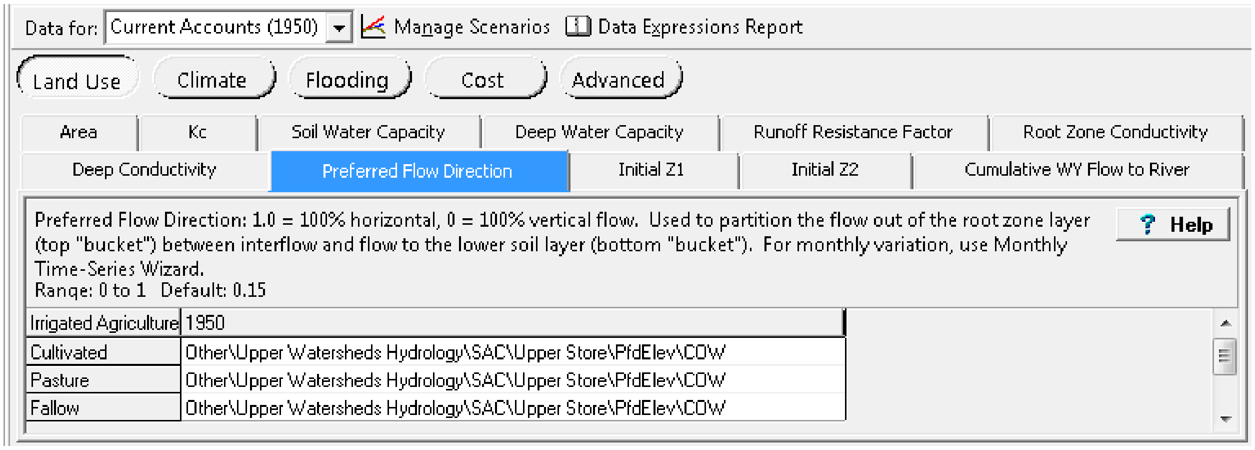


5.2.2.8 *Preferred Flow Direction*

The preferred flow direction is used to specify the division of flow from the root zone into interflow or deep percolation into the second compartment. Initially, land-use specific values were obtained from the CVPA model. During calibration it was adjusted on a sub watershed basis. These values are located in *Other Assumptions\Upper Watershed Hydrology\SAC\PfdElev.* See **upper watershed parameterization** and **upper watershed expressions** for details.

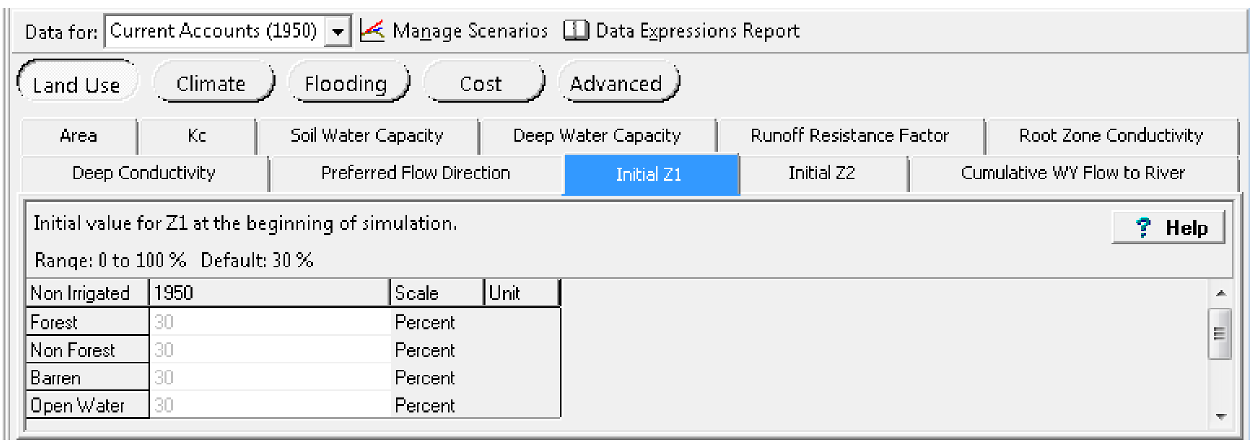






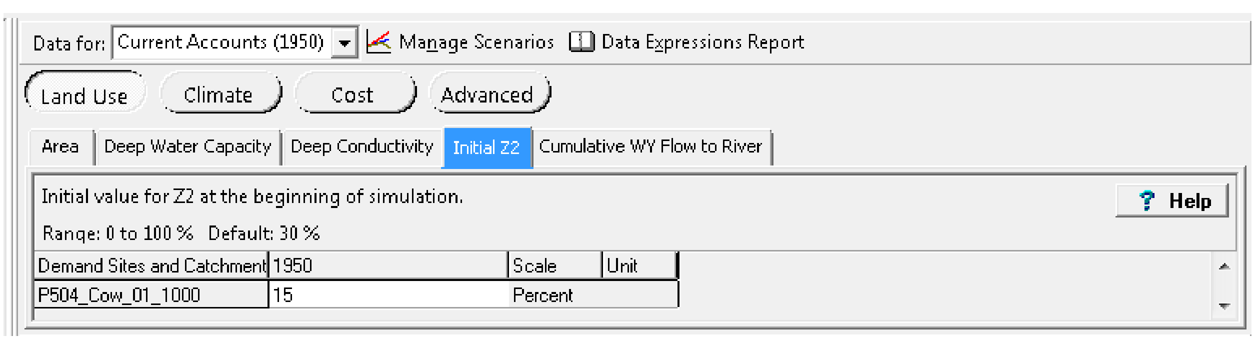
5.2.2.9 *Initial Z1*

The initial Z1 value is the initial soil moisture condition for the top compartment in the Soil Moisture Model. The default value for initial Z1 is 30%.



5.2.2.10 *Initial Z2*

The initial Z2 value is the initial soil moisture condition for the top compartment in the Soil Moisture Model. The value for initial Z2 has been set to 15%.



5.3 Data Directory

Table 5-6 provides location information in the SacWAM data directory for the datasets referenced in Chapter 5.

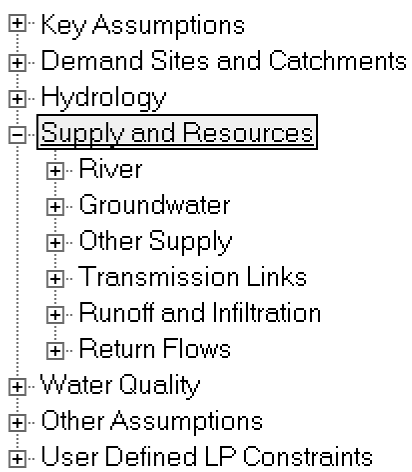
Table 5-6. File Location Information for Upper Watersheds Demand Sites and Catchments

Referenced Name	File Name(s)	File Location
catchment analysis	Catchments.xlsx	Data\Demand_Sites_and_Catchments\Upper_Watershed_Catchments
catchment land use	NLCD_all.xlsx	Data\Demand_Sites_and_Catchments\Upper_Watershed_Catchments
catchments	Catchments_final	GIS\Boundaries
climate dataset	*Individual files by coordinates*	Livneh Data
flow accumulation	nhdplusfac18b, nhdplusfac18c	GIS\Hydrology
flow direction grid	nhdplusfdr18b, nhdplusfdr18c	GIS\Hydrology
latitudes	catchment_and_DU_latitudes.xlsx	Data\Demand_Sites_and_Catchments
land-use tif	2011_SacWAM.tif	GIS\Landuse
Livneh grid	Livneh_Grid_Coords_UTM11.shp	GIS\Climate
NEDsnapshot	elev_cm_18b, elev_cm_18c	GIS\Elevation
pour point grid	upws_pts_grd	GIS\Hydrology
pour points	upws_ppts	GIS\Hydrology
reclassified elevation grid	ned_m_18b, ned_m_18c	GIS\Elevation
reclassified elevation shapefile	ned_m_upws	GIS\Elevation
simplified NLCD	NLCD_[*Region*]_Dissolve	GIS\Landuse
upper watershed expressions	UpperWShed_Expressions.xlsx	Data\Demand_Sites_and_Catchments\Upper_Watershed_Catchments
upper watershed parameterization	Upper_ws_parameterization.xlsx	Data\Other_Assumptions\Upper_Watersheds
upper watershed processor	UpperWShed_Livneh_Data_Processor.xlsm	Data\Demand_Sites_and_Catchments\Climate\Upper Watersheds
upper watershed rasters	upws_18b, upws_18c, losvaq	GIS\Boundaries
upper watersheds	Upws_final	GIS\Boundaries
WEAP input data	*Individual files by catchment*	Data\Demand_Sites_and_Catchments\Climate\WEAP Input Data

Chapter 6 Supply and Resources

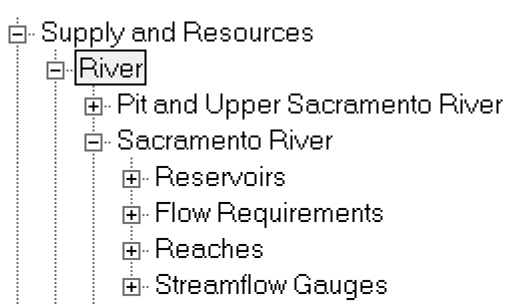
The *Supply and Resources* branch of the SacWAM data tree includes parameters relevant to transmission arcs, rivers and diversions, groundwater, runoff and infiltration, return flows, and other water supply elements including valley floor inflows, *Streamflow Gauges*, and *Reservoirs*. The *River* branch of the WEAP tree includes manmade channels and tunnels (*diversion* arcs*,* documented in Section 6.2) as well as natural streams and rivers (Section 6.1). Refer to Table 6-12 for location information of datasets relating to these parameters.

For clarity, this chapter is organized using headings that mimic the data tree in the WEAP software. It is recommended that the user navigate to the parameter of interest using the navigation pane (in Word check the “Navigation Pane” box in the “View” banner). Screenshots of the WEAP interface for each parameter are provided where possible to help the user understand where parameters are entered into the model.



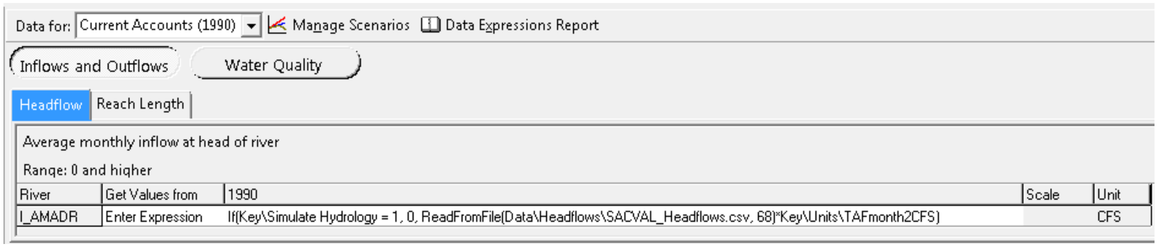
6.1 River

Both river objects (representing natural streams) and diversions objects (representing canals, tunnels, and aqueducts) appear in the WEAP tree under ‘River’. However, parameterization of river and diversion objects differ. Diversions are discussed under Section 6.2. The definition of river objects occurs at multiple levels. ‘Inflows and Outflows’ are defined for each river (the ‘Water Quality’ feature is not used in SacWAM). Additionally, a River may contain reservoirs, flow requirements, reaches, and streamflow gauges.



6.1.1 Inflows and Outflows

6.1.1.1 *Headflow*



SacWAM can run in two modes with respect to upper watershed hydrology. The first mode uses WEAP catchment objects to simulate snow accumulation, snow melt, and rainfall runoff processes. The creation of the catchments is described in Chapter 4 and Chapter 5. The second uses timeseries data of historical unimpaired flows developed by DWR to represent flows from the upper watersheds into the stream network. The model user can choose between these two methods of simulation using the parameter *Key\Simulate Hydrology.*

The WEAP “Headflow” is the inflow to the first node on a stream. Headflow can be specified either as originating from a WEAP catchment object, or with values directly input using the Read from File Method. Historical streamflow data were obtained for the Sacramento Valley Hydrologic Region from DWR, and for the San Joaquin Hydrologic Region from Reclamation. The data are stored in the csv file *Data>Headflows>SacVal_Headflows* as monthly timeseries data. The first row in this file denotes the name of the timeseries data used in SacWAM. Inflow names contain the prefix “I_” followed by a five or six letter string. The five letter string is an acronym for inflows to reservoirs or lakes. The six letter string denotes the river followed by the river mile. For example, I_SHSTA represents the inflow to Lake Shasta, and I_NFY029 represents inflow to the North Fork Yuba River at RM 29. Table 6-1 lists all historical inflows used in SacWAM and their average annual flow.

Table 6-1 Upper Watershed Inflows

Inflow Arc	Description	Type[1]	Av. Annual Flow (TAF)[2]
I_ALD001	Alder Creek near Whitehall	Stream inflow	28
I_ALMNW	Lake Almanor and Mountain Meadows Reservoir	Reservoir inflow	728
I_AMADR	Amador Reservoir	Reservoir inflow	29
I_ANT011	Antelope Creek near Red Bluff	Stream inflow	101
I_ANTLP	Antelope Reservoir	Reservoir inflow	33
I_BCC014	Big Chico Creek near Chico	Stream inflow	101
I_BCN010	Bear Creek (North) near Millville	Stream inflow	60
I_BKILD	Bucks Island Lake	Stream inflow	20
I_BLKBT	Black Butte Lake	Local reservoir inflow	205
I_BOWMN	Bowman Lake	Reservoir inflow	93
I_BRC003	Bear Creek above Holsten Chimney	Stream inflow	34
I_BRR023	Camp Far West Reservoir	Local reservoir inflow	93
I_BRYSA	Lake Berryessa	Reservoir inflow	362
I_BTC048	Butte Creek	Stream inflow	245
I_BTL006	Battle Creek near Cottonwood	Stream inflow	351
I_BTVLY	Butt Valley Reservoir	Reservoir inflow	75
I_BUKSL	Bucks Lake	Reservoir inflow	85
I_CAPLS	Caples Lake	Reservoir inflow	27
I_CCH053	Cache Creek above Rumsey	Stream accretion	55
I_CLR011	Clear Creek near Igo	Stream accretion	46
I_CLR025	Whiskeytown Lake	Reservoir inflow	285
I_CLRLK	Clear Lake	Reservoir inflow	436
I_CLV026	Calaveras River at Bellota	Stream inflow	8
I_CMBIE	Combie Reservoir	Local reservoir inflow	31
I_CMCHE	Camanche Reservoir	Local reservoir inflow	11
I_CMP001	Camp Creek at mouth	Stream inflow	12
I_CMP012	Camp Creek at Camp Creek Diversion Tunnel	Stream inflow	32
I_CMPFW	Camp Far West Reservoir	Local reservoir inflow	16
I_COW014	Cow Creek near Millville	Stream inflow	420
I_CSM035	Cosumnes River at Michigan Bar	Stream accretion	305
I_CWD018	North Fork and Middle Fork Cottonwood Creek near Olinda	Stream inflow	298
I_DAVIS	Lake Davis	Reservoir inflow	26
I_DCC007	Duncan Canyon Creek	Stream inflow	28
I_DEE023	Deer Creek	Stream inflow	33
I_DER001	Deer Creek near Smartville	Stream accretion	29
I_DER004	Deer Creek at Wildwood Dam	Stream accretion	33
I_DHC001	Dry Creek and Hutchinson Creek	Stream inflow	54
I_DRC012	Deer Creek near Vina	Stream inflow	231
I_DSC035	Dry and Sutter creeks	Stream inflow	65
I_ELD027	Elder Creek near Paskenta	Stream inflow	68
I_ELIMP	Echo Lake Conduit	Inter-basin import	2
I_ENF011	East Branch of North Fork Feather River near Rich Bar	Stream accretion	52
I_ENGLB	Englebright Reservoir	Stream inflow	147
I_EPARK	East Park Reservoir inflow	Reservoir inflow	66
I_FOLSM	Folsom Lake	Local reservoir inflow	249
I_FRDYC	Fordyce Lake	Reservoir inflow	87
I_FRMAN	Lake Frenchman	Reservoir inflow	23
I_FRMDW	French Meadows Reservoir	Reservoir inflow	114
I_GRZLY	Grizzly Creek	Stream inflow	52
I_HHOLE	Hell Hole Reservoir	Local reservoir inflow	207
I_HON021	South Fork Honcut Creek near Bangor	Stream inflow	24
I_ICEHS	Ice House Reservoir	Reservoir inflow	56
I_INDVL	Indian Valley Reservoir	Reservoir inflow	111
I_JKSMD	Jackson Meadows Reservoir	Reservoir inflow	76
I_JNKSN	Jenkinson Lake	Reservoir inflow	17

Table 6-1 Upper Watershed Inflows cont.

Inflow Arc	Description	Type[1]	Av. Annual Flow (TAF) [2]
I_KSWCK	Sacramento River below Keswick Dam	Stream accretion	175
I_LBEAR	Lower Bear Reservoir	Reservoir inflow	73
I_LCC038	Little Chico Creek near Chico	Stream inflow	22
I_LDC029	Little Dry Creek	Stream inflow	26
I_LGRSV	Little Grass Valley Reservoir	Reservoir inflow	78
I_LJC022	Littlejohn and Rock Creek at Farmington Reservoir	Reservoir inflow	52
I_LKVLY	Lake Valley Reservoir	Reservoir inflow	9
I_LNG000	Long Creek Canyon at mouth	Stream inflow	74
I_LOONL	Loon Lake	Reservoir inflow	22
I_LOSVQ	Los Vaqueros Reservoir	Reservoir inflow	1
I_LST007	Sly Creek Reservoir	Reservoir inflow	75
I_LWSTN	Lewiston Lake	Local reservoir inflow	23
I_MERLC	Merle Collins Reservoir	Reservoir inflow	48
I_MFA001	Middle Fork American River near Auburn local inflow	Stream accretion	245
I_MFA023	Middle Fork American River near Foresthill	Stream accretion	0
I_MFA036	Middle Fork American River at Interbay Diversion Dam	Stream accretion	51
I_MFF073	Middle Fork Feather River near Potola	Stream accretion	115
I_MFF019	Middle Fork Feather River near Merrimac	Stream accretion	962
I_MFM010	Middle Fork Mokelumne near West Point	Stream inflow	47
I_MFY013	Middle Fork Yuba River above Our House Diversion Dam	Stream accretion	152
I_MLC006	Mill Creek near Los Molinos	Stream inflow	217
I_MNS000	Minor northeast streams	Stream inflow	237
I_MOK079	Mokelumne River at Mokelumne Hill	Stream accretion	70
I_MSH015	Marsh Creek	Stream inflow	14
I_NBLDB	New Bullards Bar Reservoir	Local reservoir inflow	402
I_NFA022	North Fork American River at North Fork Dam local inflow	Stream accretion	219
I_NFA054	North Fork American River	Stream inflow	353
I_NFF027	North Fork Feather River at Pulga	Stream accretion	754
I_NFM006	North Fork Mokelumne below Tiger Creek Reservoir	Stream accretion	13
I_NFY029	North Fork Yuba River below Goodyears Bar	Stream inflow	539
I_NHGAN	New Hogan Reservoir	Reservoir inflow	154
I_OGN005	Oregon Creek at Log Cabin Diversion Dam	Stream inflow	53
I_OROVL	Lake Oroville	Local reservoir inflow	282
I_PARDE	Pardee Reservoir	Local reservoir inflow	11
I_STMPY	Stumpy Meadows Reservoir	Reservoir inflow	22
I_PLM001	Plum Creek Inflow	Stream inflow	7
I_PYN001	Paynes Creek and Sevenmile Creek	Stream inflow	53
I_RLLNS	Rollins Reservoir natural inflow	Local reservoir inflow	160
I_RUB001	Local Inflows to Rubicon River	Stream accretion	100
I_RBCON	Rubicon Lake	Reservoir Inflow	75
I_RVPHB	Round Valley and Philbrook lakes	Reservoir inflow	20
I_SCOTF	Scotts Flat Reservoir	Local reservoir inflow	33
I_SCW008	South Fork Cottonwood Creek near Olinda	Stream inflow	178
I_SFA021	South Fork American River near Placerville	Stream accretion	107
I_SFA035	South Fork American River near Camino	Stream accretion	171
I_SFA056	South Fork American River at Kyburz	Stream inflow	247
I_SFD003	South Fork Deer Creek at Wildwood Dam	Stream inflow	8
I_SFF008	South Fork Feather at Enterprise	Stream accretion	21
I_SFF011	South Fork Feather River at Ponderosa Dam	Stream accretion	94
I_SFM006	South Fork Mokelumne near West Point	Stream inflow	56
I_SFR005	South Fork Rubicon River Inflow	Stream inflow	80
I_SFY007	South Fork Yuba River at Jones Bar	Stream accretion	207
I_SGRGE	Stony Gorge Reservoir	Local reservoir inflow	165
I_SHSTA	Shasta Lake	Reservoir inflow	5,667
I_SILVR	Silver Lake	Reservoir inflow	26

Table 6-1 Upper Watershed Inflows contd.

Inflow Arc	Description	Type[1]	Av. Annual Flow (TAF)[2]
I_SLT009	Slate Creek at Slate Creek Diversion Dam	Stream inflow	141
I_SLTSP	Salt Springs Reservoir	Reservoir Inflow	332
I_SPLDG	Lake Spaulding	Local reservoir inflow	306
I_THM028	Thomes Creek at Paskenta	Stream inflow	217
I_TRNTY	Trinity Reservoir (Claire Engle Lake)	Reservoir inflow	1,267
I_UNVLY	Union Valley Reservoir	Reservoir inflow	168
I_WBF006	West Branch Feather River near Yankee Hill	Stream accretion	69
I_WBF015	West Branch Feather River at Miocene Diversion Dam	Stream accretion	148
I_WBF030	West Branch Feather River at Hendricks Diversion Dam	Stream accretion	96
I_WLF013	Wolf Creek at Tarr Ditch Diversion Dam	Stream inflow	19

Notes:
[1] Reservoir inflow = total natural inflow to reservoir or lake.
Local reservoir inflow = natural inflow to reservoir or lake from a portion of watershed adjacent to the water body.
Stream inflow = natural flow/unimpaired flow at stream location.
Stream accretion = accretion to stream or river between upstream inflow location and this location.
[2] Flows averaged over Water Years 1922-2009.
Key: TAF = thousand acre-feet

Only in limited cases are streamflow records available over the entire period of simulation. For the majority of streams, historical timeseries data have been extended using various statistical methods assuming stationarity over the historical period. Methods used to develop each inflow are summarized in Table 6-2. These methods are as follows:

- Direct gauge measurement: Stream gauge data exist at the watershed outflow point for water years 1922 through 2009.
- Streamflow correlation: Stream gauge data exist at the watershed outflow point for only a limited period between water years 1922 and 2009. Gauge data are extended through linear correlation of annual flows with streamflow records from adjacent watersheds. Double mass plots of monthly flows are used to check that a constant (and linear) relationship exists between the dependent and independent variables. Annual synthetic flows are disaggregated to a monthly time step based on the cumulative fraction of annual runoff that has occurred by the end of month, while attempting to preserve the shape of the hydrograph of the dependent watershed.
- Proportionality: No gauge data exist for the watershed. It is assumed that runoff is proportional to the product of drainage area and average annual precipitation depth over the watershed.[9] Outflow is determined through association of the watershed with a similar, but gauged watershed and the use of multiplicative factors representing the ratio of watershed areas and ratio of precipitation depths.
- Mass balance: Typically, this method is used when watersheds have significant storage regulation. Reservoir operating records of dam releases and reservoir storage, together with estimated reservoir evaporation, are used to estimate inflows to the reservoir.

[9] Determined using PRISM data of the 30-year average annual precipitation for 1971-2000 (PRISM, 2013).

Table 6-2 Data Sources and Calculation Methods for Upper Watershed Inflows

SacWAM Inflow	Observed Period	Agency	Gauge ID	Flow Correlation	Propor-tionality	Mass Balance
I_ALMMW	10/21 - present	USGS	11399500			●
I_AMADR	–	–	–		●	
I_ANT011	10/40 - 09/82[2]	USGS	11379000	●		
I_ANTLP	10/30 - 09/93	USGS	11401500	●		●
I_BCC014	10/21 - 09/86	USGS	11384000	●		●
I_BCN010	10/59 - 09/67	USGS	11374100	●		
I_BKILD	11/90 - present	USGS	11428400	●		●
I_BLKBT	01/53 - present	USACE	Res. Report of Operations	●		●
I_BOWMN	02/27 - present	USGS	11416500	●		
I_BRC003	10/98 - present	USGS	11451715	●	●	
I_BRR023	–	–	–	●	●	●
I_BRYSA	01/57 - present	Reclamation	Res. Report of Operations	●		●
I_BTC048	10/30 - present	USGS	11390000			●
I_BTL006	10/40 - 09/61	USGS	11376500	●		
I_BTL006	10/61 - present	USGS	11376550			
I_BTVLY	10/36 - present	USGS	11400500	●	●	
I_BUKSL	10/80 - present	USGS	11403530	●		●
I_CAPLS	10/22 - 09/92	USGS	11437000	●		●
I_CCH053	10/60 - present	USGS	11451760	●	●	●
I_CLR011	10/40 - present	USGS	11372000	●		●
I_CLR025	10/64 - present	Reclamation	Res. Report of Operations	●	●	
I_CLRLK	10/44 - present	USGS	11451000			●
I_CLV026	–	–	–		●	
I_CMBIE	–	–	–	●	●	●
I_CMCHE	–	–	–		●	
I_CMP001	10/56 - 09/04	USGS	11333000	●		
I_CMP012	10/49 - 09/54	USGS	11331500	●	●	
I_CMPFW				●	●	●
I_COW014	10/49 - present	USGS	11374000	●	●	
I_CSM035	10/21 - present	USGS	11335000			●
I_CWD018	09/71 - 09/86	USGS	11375810	●		
I_DAVIS	10/25 - 09/80, 12/67 - present	USGS, DWR	11391500, Res. Report of Operations	●	●	
I_DCC007	09/60 - present	USGS	11427700	●		●
I_DEE023	10/60 - 09/77	USGS	11335700	●	●	
I_DER001	10/35 - present	USGS	1418500			
I_DER004	–	–	–		●	
I_DHC001	–	–	–		●	
I_DRC012	10/21 - present	USGS	11383500	Data for all years		
I_DSC035	10/61 - 09/70, 10/35 - 09/41	USGS, USGS	11326300, 11327000	●	●	
I_ELD027	10/48 - present	USGS	11379500	●		
I_ELIMP	08/23 - present	USGS	11434500	●		
I_ENF011	10/50 - 09/60	USGS	11403000	●		●

Table 6-2 Data Sources and Calculation Methods for Upper Watershed Inflows, contd.

SacWAM Inflow	Observed Period	Agency	Gauge ID	Flow Correlation	Propor-tionality	Mass Balance
I_ENGLB	10/21 - 09/41, 10/41 - present	USGS, USGS	11418000, 11419000	●		●
I_EPARK	10/21 - present	Reclamation	Res. Report of Operations			●
I_FOLSM	10/21 - present, 02/55 - present	USGS, Reclamation	USGS Res. Report of Operations			●
I_FRDYC	07/66 - present	USGS	11414100	●		●
I_FRMAN	10/65 - present	DWR	Res. Report of Operations	●		●
I_FRMDW	10/64 - present	USGS	11427500	●		●
I_GRZLY	10/85 - present	USGS	11404300	●		●
I_HHOLE	10/85 - present	USGS	11428800	●		●
I_HON021	10/50 - 09/86	USGS	11407500	●		
I_ICEHS	10/1923 - present	USGS	11441500	●		●
I_INDVL	10/74 - present	USGS	11451300	●		●
I_JKSMD	10/26 - present	USGS	11407900	●		●
I_JNKSN	10/46 - 09/54	USGS	11332500	●		
I_KSWCK	10/38 - present	USGS	11370500			●
I_LBEAR	–	–	–		●	
I_LCC038	02/59 - present	DWR	A04910	●		●
I_LCC039	02/59 - 09/93	DWR	A04280			
I_LDC029	–	–	–		●	
I_LGRSV	10/63 - present	USGS	11395030	●		●
I_LJC022	10/51 - 09/95	USACE	multiple data sources	●		●
I_LKVLY	–	–	–		●	
I_LNG000	10/66 - 09/92	USGS	11433100	●	●	●
I_LOONL	10/62 - present	USGS	11429500	●		●
I_LOSVQ	10/97 - present	CCWD		●		
I_LST007	10/73 - present	USGS	11396000	●		●
I_LWSTN	10/21 - present	USGS	11525500	●		●
I_MERLC	10/63 -present	BVID	Res. Report of Operations	●		●
I_MFA001	10/21 - 09/85	USGS	11433500	●		●
I_MFA036	10/65 - present	USGS	11427770	●		●
I_MFF019	10/51 - 09/86	USGS	11394500	●		
I_MFF073	10/68 - 09/80	USGS	11329100	●		●
I_MFM010	10/21 - present	USGS	11317000			
I_MFY013	10/68 - present	USGS	11408870			●
I_MLC006	10/28 - present	USGS	11381500	●		
I_MNS000	–	–	–		●	
I_MOK079	10/27 - present	USGS	11319500			●
I_MSH015	04/53 - 09/83	USGS	11337500			
I_NBLDB	10/66 - 09/40	USGS	11413520	●		●
I_NFA022	10/21 - 09/41, 10/41 - present	USGS, USGS	11426500, 11427000		●	●
I_NFA054	10/21 - 09/41, 10/41 - present	USGS, USGS	11426500, 11427000		●	●
I_NFF027	10/21 - present	USGS	11404500	●		●
I_NFM006	09/84 - present	USGS	11316700	●		●

Table 6-2 Data Sources and Calculation Methods for Upper Watershed Inflows, contd.

SacWAM Inflow	Observed Period	Agency	Gauge ID	Flow Correlation	Propor-tionality	Mass Balance
I_NFY029	10/30 - present	USGS	11413000	●	●	
I_NHGAN	10/63 - present	USACE	Res. Report of Operations	●		●
I_OGN005	10/21 – 09/69, 09/68 - present	USGS, USGS	11409500	●	●	●
I_OROVL	10/21 - present, 10/67 - present	USGS, DWR	11407000, Res. Report of Operations			●
I_PARDE	–	–	–	●	●	●
I_PLM001	10/22 - 09/39	USGS	11440500	●		
I_PYN001	10/49 - 09/66	USGS	11377500	●	●	
I_RBCON	10/91 - present	USGS	11427960	●		●
I_RLLNS	04/50 - present	USGS	11422500	●	●	●
I_RUB001	10/58 – 09/84	USGS	11433200	●		●
I_RVPHB	–	–	–	●	●	●
I_SCOTF	–	–	–		●	●
I_SCW008	12/76 - 09/86	USGS	11375870	●		
I_SFA021	10/64 - present	USGS	11444500	●		●
I_SFA035	10/22 - present	USGS	11443500	●		●
I_SFA056	10/22 - present	USGS	11439500	●		●
I_SFD003	–	–	–		●	
I_SFF008	10/21 - 09/66	USGS	11397000	●		●
I_SFF011	10/21 - 09/66	USGS	11397000	●		●
I_SFM006	10/21 - present	USGS	11317000	●		
I_SFR005	10/62 - present	USGS	11430000	●		●
I_SFY007	10/40 - present	USGS	11417500	●		
I_SGRGE	11/28 - present	Reclamation	Res. Report of Operations			●
I_SHSTA	10/25 - 09/42 01/44 - present	USGS, Reclamation	11369500, Res. Report of Operations		●	●
I_SILVR	10/22 - present	USGS	11436000	●		●
I_SLT009	10/60 - present	USGS	11413300	●		●
I_SLTSP	10/27 - present	USGS	11314500	●		●
I_SPLDG	12/65 - present	USGS	11414250	●		●
I_STMPY	04/46 - 09/60	USGS	11432500	●		
I_THM028	10/21 - 09/96	USGS	11382000	●		
I_TRNTY	10/21 - present, 10/61 - present	USGS, Reclamation	11525500, Res. Report of Operations	●		●
I_UNVLY	10/61 - present	USGS	11441002			
I_WBF006	10/30 - 09/63	USGS	11406500	●	●	●
I_WBF015	10/30 - 09/63	USGS	11406500	●	●	●
I_WBF030	10/30 - 09/63	USGS	11406500	●	●	●
I_WLF013	–	–	–	●	●	●

Key: cfs=cubic feet per second; DWR=California Department of Water Resources; PG&E=Pacific Gas and Electric; USGS=United States Geological Survey; WBA=Water Budget Area

6.1.1.2 *Fraction Diverted*

The fraction diverted for rivers is only applicable to the Old River and is discussed in Section 7.2.5.2 in Chapter 7 on Other Assumptions.

6.1.2 Reservoirs

The following sections apply to the majority of the reservoirs in SacWAM. However, Camino Reservoir, Caples Lake, Chili Bar Reservoir, Silver Lake, Slab Creek Reservoir, Farmington Reservoir, Rock Creek Reservoir, Clifton Court Forebay, and Lake Amador are not operated in the model and therefore bear blank expressions for many of the parameters. The purpose of these reservoirs in SacWAM is solely to orient SacWAM users when viewing the schematic.

The San Luis Reservoir is represented by two reservoirs: CVP_San Luis and SWP_San Luis in order to represent and simulate the CVP and SWP share of the facility. Operations of San Luis Reservoir is discussed in detail in the Other Assumptions chapter, Section 7.2.1.

6.1.2.1 *Reservoir Evaporation*

For SacWAM a user-defined set of parameters was added to the model in order to calculate the reservoir evaporation. These parameters are located in the Reservoir Evaporation tab of the Reservoirs interface. The calculation of reservoir evaporation is made using the Modified Hargreaves Equation (Droogers and Allen, 2002):

D*0.0013*(So)*(Tave[C] +17.0)*(Tmax[C]-Tmin[C]-0.0123*P [mm])^0.76 Equation 6-1

where:

D = days in the time step;

So = extra-terrestrial solar radiation;

Tave = average temperature for the time step;

Tmax = maximum temperature for the time step, 1.4 x Tave;

Tmin = minimum temperature for the time step, 0.6 x Tave.

Precipitation, Tave, Tmin, and Tmax

Precipitation and average temperature values are taken from the catchments in which the reservoirs are located.

Latitude

Latitudes for each reservoir were determined using GIS.

Reference Evap

The reference evaporation is calculated using Equation 3-2.

JDay

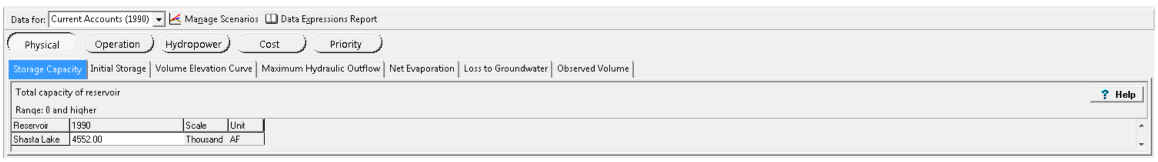
JDay stands for Julian Day. The default values in WEAP are the middle day of the month as counted by the Julian calendar, where January 1 is 1, January 31 is 31, February 1 is 32…and December 31 is 365 (in a non-leap year).

del, dr, ws, and *So*

Solar declination (*del*), the relative distance between Earth and the sun (*dr*), the sunset hour angle (*ws*), and solar radiation (*So*) are affect the reference evaporation expression; all use default WEAP expressions.

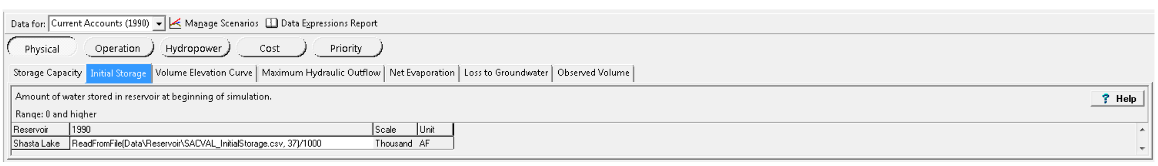
6.1.2.2 *Physical*

Storage Capacity



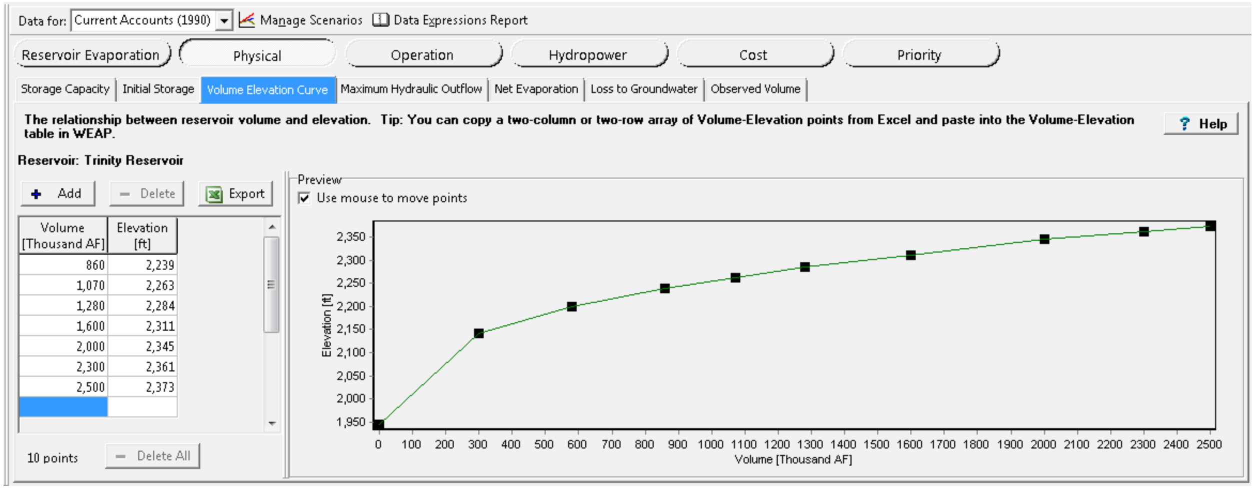
Storage Capacity data for reservoirs were obtained from CDEC (DWR, 2014d). They are given in TAF in SacWAM (*Supply and Resources**Rivers**Reservoirs**Physical**Storage Capacity*). For more information, see **reservoir storage capacity**.

Initial Storage



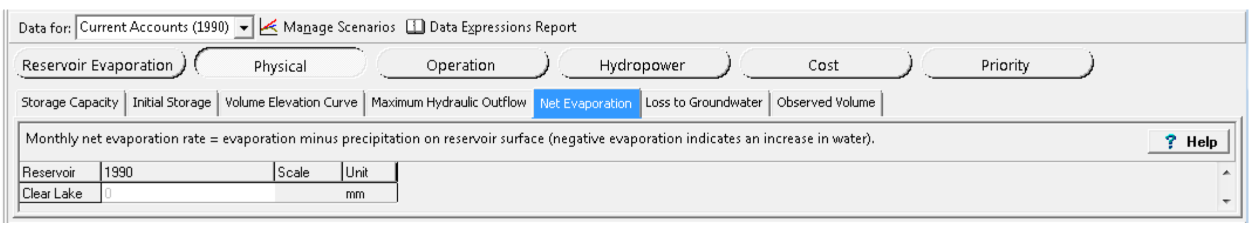
Initial Storage data for reservoirs were obtained from CDEC and represent historical October 1 storage volumes (DWR, 2014d). These values are given in TAF (*Supply and Resources**Rivers**Reservoirs**Physical* *Initial Storage*). For more information, see **reservoir storage capacity**.

Volume Elevation Curve



Volume Elevation Curve data for reservoirs were obtained from a variety of sources. They relate reservoir volume in TAF to reservoir water surface elevation in feet (*Supply and Resources\Rivers\Reservoirs\Physical\Volume Elevation Curve*). This information is used to calculate the reservoir area for use in simulating reservoir evaporation. For complete data, see **volume elevation curve**.

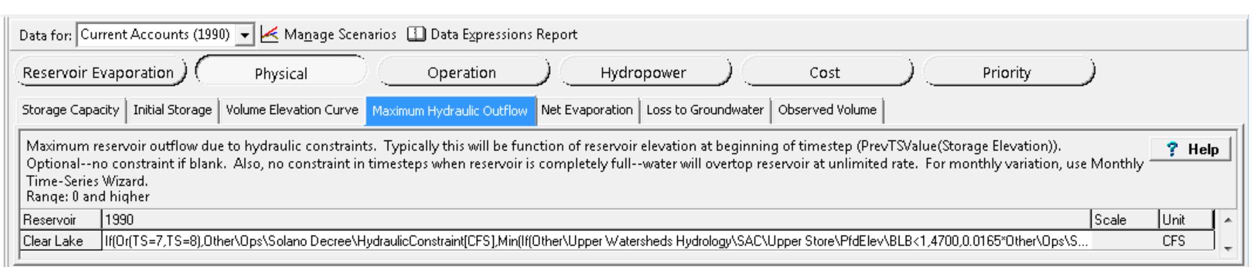
Net Evaporation



This parameter is used to simulate evaporation from the water surface of the reservoir.

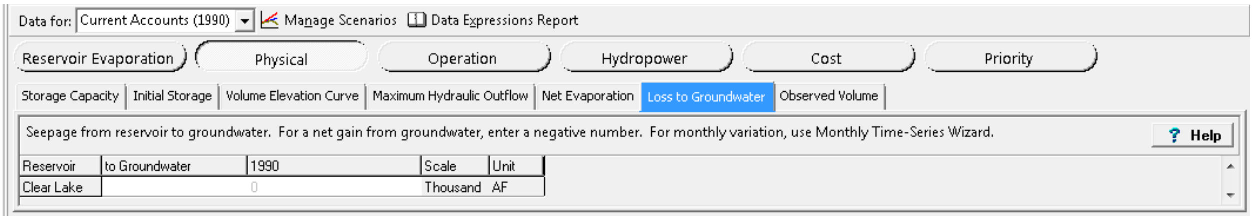
In WEAP this parameter is often treated as the net of evaporation and precipitation that occurs on the reservoir surface. However, in SacWAM the catchments contain the area of the reservoirs and therefore account for the precipitation that falls on the reservoir. For this reason, the Net Evaporation parameter only contains the estimated reference evaporation calculated in the *Reference Evap* parameter under the Reservoir Evaporation tab.

Maximum Hydraulic Outflow



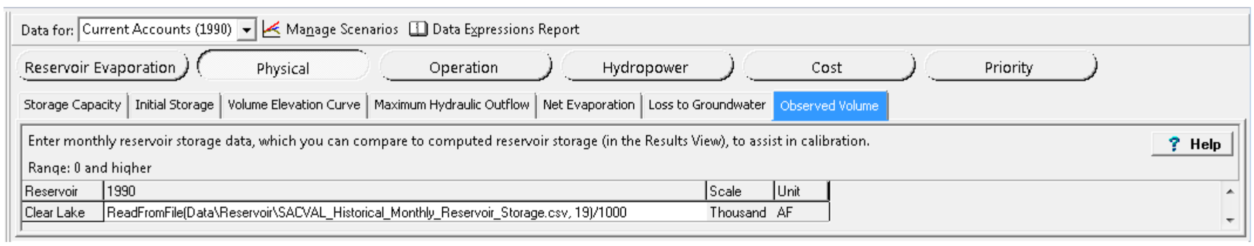
This parameter restricts the flow of water out of a reservoir. In SacWAM this has been implemented on Clear Lake as part of the Solano Decree logic, on Whiskeytown reservoir, and on Los Vaqueros reservoir.

Loss to Groundwater



No reservoir losses to groundwater are simulated in SacWAM.

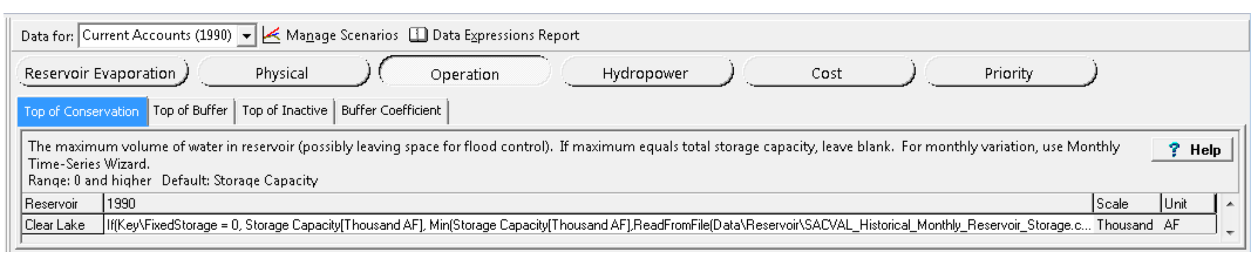
Observed Volume



Historical *Observed Volumes* for reservoirs are read from the file Data\Reservoir\SACVAL_Historical_Monthly_Reservoir_Storage.csv stored in the WEAP model directory. The data were taken from CDEC and can be found in **reservoir storage capacity**.

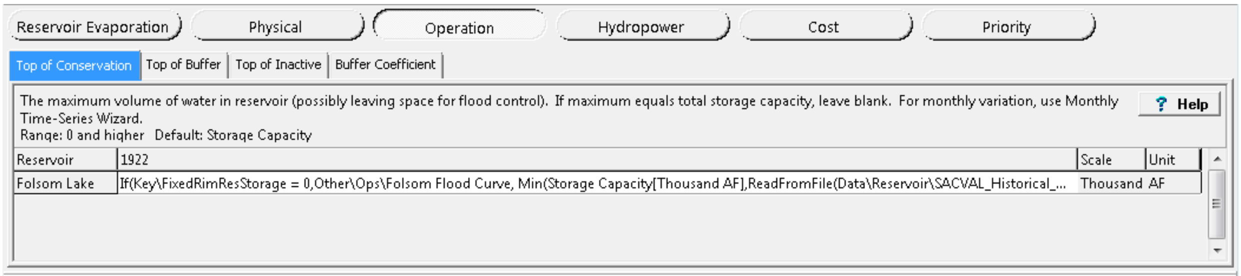
6.1.2.3 *Operation*

The operations of reservoirs, tunnels, and canals in the upper watersheds have been kept relatively simple and do not fully reflect the complexity that exists in the operations of this infrastructure in the real system. This relatively simple approach was implemented as the operations of the upper watershed infrastructure is buffered by the large volume of storage available in the rim reservoirs. For now, the operations of the reservoirs and diversions (tunnels, canals) is set equal to the average monthly storage or flow.



Average monthly storage values (1970-2009) were loaded into Top of Conservation and Top of Inactive. These parameters force the reservoir to maintain operations at a given average monthly value, and can be turned off and on using the *Simulate Operations* Key Assumption. These average monthly values are derived from CDEC (DWR, 2014d) or USGS data.

Top of Conservation



The top of conservation parameter is used to place an upper limit on the conservation storage in a reservoir. In SacWAM, reservoirs are divided into “Rim” reservoirs (Table 6-3) or “Upper Watershed” reservoirs (Table 6-4). Generally, the “Rim” reservoirs are the terminal reservoirs on their respective streams. These reservoirs have a switch controlled by the Key Assumption *FixedRimResStorage* that allows the user to set the monthly storage in these reservoirs equal to the historical record. This is useful for calibration purposes. The “Upper Watershed” reservoirs are largely hydropower reservoirs located upstream from the terminal reservoirs. In SacWAM the user can opt to have the storage in these reservoirs set equal to the 1970-2009 average monthly value of storage. This allows for a simple representation of the hydropower operations that occur in these reservoirs. This setting is through the Key Assumption *FixedUpperResStorage*. For more information, see **reservoir storage capacity**.

Table 6-3. Rim Reservoirs

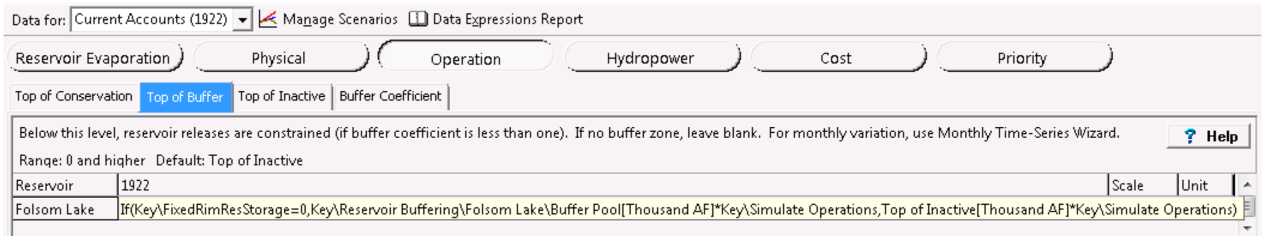
Shasta Lake	Oroville Reservoir
New Bullards Bar Reservoir	Folsom Lake
Pardee Reservoir	Camanche Reservoir
Trinity Reservoir	New Hogan Reservoir
Black Butte Reservoir	Whiskeytown Reservoir
Keswick Reservoir	Lake Natoma
Clear Lake	Lewiston Lake
Lake Berryessa	Thermalito Afterbay
Camp Far West	Jenkinson Lake
East Park Reservoir	Stony Gorge Reservoir
Indian Valley Reservoir	Englebright Reservoir
Los Vaqueros Reservoir	

Table 6-4. Upper Watershed Reservoirs Constrained to Average Historical Storage

Rollins Reservoir	Lake Combie
Frenchman Lake	Scotts Flat
Sly Creek Reservoir	French Meadows
Jackson Meadows Reservoir	Lake Spaulding
Little Grass Valley	Bowman Lake
Lake Fordyce	Union Valley Reservoir
Ice House Reservoir	Hell Hole Reservoir
Loon Lake Reservoir	Lake Almanor
Butt Valley	Bucks Lake
Lake Davis	Merle Collins Reservoir

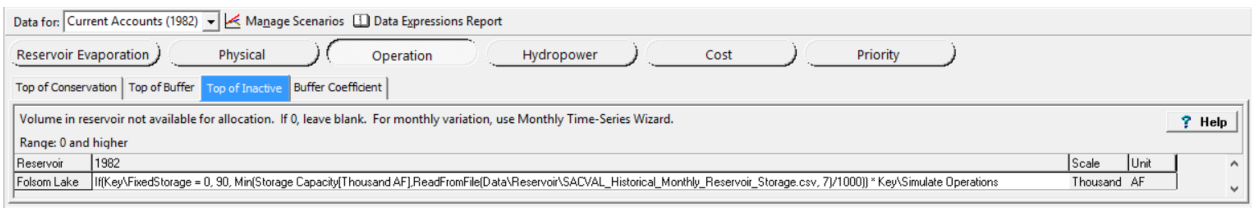
Top of conservation for Shasta varies from year to year depending on hydrologic conditions. Therefore, when the (i.e. *FixedRimResStorage*=0), Top of Conservation values are read from a file of CalSim II data that reflect the historical conditions.

Top of Buffer



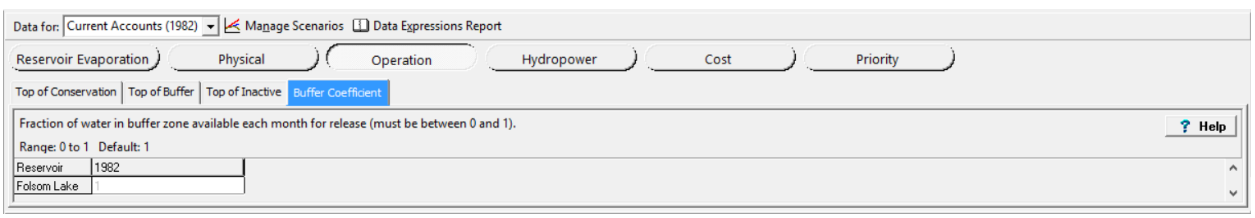
The top of buffer parameter is used to set the upper limit of the buffer pool. If the reservoir is operating in the buffer pool then the reservoir will release only the volume of water available multiplied by the buffer coefficient. For the major rim reservoirs, expressions have been added to the Top of Buffer parameter that allow the user to set buffer pool volumes. These values are set in *Key Assumptions\Reservoir Buffering* (see Section 9.11).

Top of Inactive



The top of inactive parameter is used to specify the upper limit of the dead pool storage. Similar to the top of conservation, some reservoirs have this parameter constrained to average historical storage in order to simulate operations (Table 6-3). The remainder have a fixed volume of dead pool storage. For more information, see **reservoir storage capacity**.

Buffer Coefficient



The buffer coefficient parameter is used to specify the fraction of the buffer pool that is available to meet demands. Similar to Top of Buffer, there is an option to set this parameter for the major rim reservoirs using the in *Key Assumptions\Reservoir Buffering* (see Section 9.11).

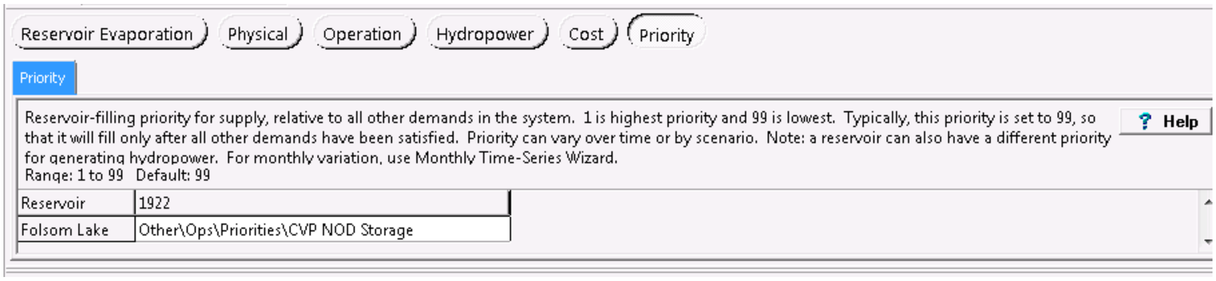
6.1.2.4 *Hydropower*

The *Hydropower* WEAP feature is not used in SacWAM.

6.1.2.5 *Cost*

The *Cost* WEAP feature is not used in SacWAM.

6.1.2.6 *Priority*



Priorities for reservoirs, demand sites and catchments, and flow requirements are discussed in the Other Assumptions chapter, Section 7.2.1. Demand priorities are assigned to reservoirs for water storage as well as to other consumptive and non-consumptive (i.e. flow requirement) demands. These priorities are also considered relative to the rest of the demand priority structure (Section 7.2.1), such that WEAP will prefer to store water if the storage priority is higher (i.e. has a lower numeric value) than another demand. When releasing water from storage to meet downstream demands, WEAP will release first from reservoirs with lower demand priority. Also, if reservoirs share the same demand priority, then WEAP will attempt to balance these reservoirs as a percentage of their potential storage (i.e. top of conservation storage). Priority values for reservoirs in SacWAM are primarily defined relative to Demand Groups described in Table 7-29. Expressions of reservoir priority and their associated values are presented in Section Table 6-5.

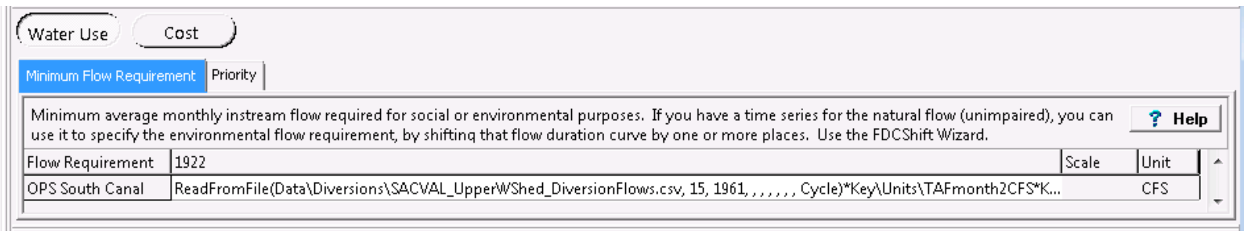
Table 6-5. SacWAM Reservoir Priority Structure

Reservoir	River	Priority	Expression
SWP San Luis Reservoir	SWP San Luis Conveyance	56,52	SWP SOD Storage ab/bw Rule Curve
Clifton Court Forebay	Old River	52	SWP SOD Storage bw Rule Curve
Oroville Reservoir	Feather River	52	SWP NOD Storage
Thermalito Afterbay	Power Canal	52	SWP NOD Storage
CVP San Luis Reservoir	CVP San Luis Conveyance	54,45	CVP SOD Storage ab/bw Rule Curve
Folsom Lake	American River	53	CVP NOD Storage
Keswick Reservoir	Sacramento River	53	CVP NOD Storage
Lake Natoma	American River	53	CVP NOD Storage
Shasta Lake	Sacramento River	53	CVP NOD Storage
Whiskeytown Reservoir	Clear Creek	53	CVP NOD Storage
Lewiston Lake	Trinity River	21	CVP NOD Storage - 25
Trinity Reservoir	Trinity River	21	CVP NOD Storage - 25
Los Vaqueros Reservoir	Kellogg Creek	14	Urban NonProject + 1
Black Butte Reservoir	Stony Creek	12	NonProject Trib Storage
Camanche Reservoir	Mokelumne River	12	NonProject Trib Storage
Camp Far West	Bear River	12	NonProject Trib Storage
Clear Lake	Cache Creek	12	NonProject Trib Storage
East Park Reservoir	Little Stony Creek	12	NonProject Trib Storage
Englebright Reservoir	Yuba River	12	NonProject Trib Storage
Farmington Reservoir	Littlejohns Creek	12	NonProject Trib Storage
Indian Valley Reservoir	North Fork Cache Creek	12	NonProject Trib Storage
Lake Berryessa	Putah Creek	12	NonProject Trib Storage
New Bullards Bar Reservoir	Yuba River	12	NonProject Trib Storage
New Hogan Reservoir	Calaveras River	12	NonProject Trib Storage
Stony Gorge Reservoir	Stony Creek	12	NonProject Trib Storage
Pardee Reservoir	Mokelumne River	11	NonProject Trib Storage - 1
EBMUD Terminal Reservoirs	Mokelumne Aqueduct	9	
PGandE Upper Watershed Reservoirs	North Fork Mokelumne River	6	Upper Watershed Reservoirs + 1
Bowman Lake	Canyon Creek	5	Upper Watershed Reservoirs
Camino Reservoir	Silver Creek	5	Upper Watershed Reservoirs
Caples Lake	Caples Creek	5	Upper Watershed Reservoirs
Chili Bar Reservoir	South Fork American River	5	Upper Watershed Reservoirs
French Meadows	Middle Fork American River	5	Upper Watershed Reservoirs
Hell Hole	Rubicon River	5	Upper Watershed Reservoirs
Ice House	South Fork Silver Creek	5	Upper Watershed Reservoirs
Jackson Meadows Reservoir	Middle Fork Yuba River	5	Upper Watershed Reservoirs
Jenkinson Lake	Sly Park Creek	5	Upper Watershed Reservoirs
Lake Almanor	North Fork Feather River	5	Upper Watershed Reservoirs
Lake Amador	Jackson Creek	5	Upper Watershed Reservoirs
Lake Combie	Bear River	5	Upper Watershed Reservoirs
Lake Fordyce	Fordyce Creek	5	Upper Watershed Reservoirs
Lake Spaulding	South Fork Yuba River	5	Upper Watershed Reservoirs
Little Grass Valley Reservoir	South Fork Feather River	5	Upper Watershed Reservoirs
Loon Lake	Gerle Creek	5	Upper Watershed Reservoirs
Merle Collins Reservoir	French Dry Creek	5	Upper Watershed Reservoirs
Rock Creek Reservoir	Wise Canal	5	Upper Watershed Reservoirs
Rollins Reservoir	Bear River	5	Upper Watershed Reservoirs
Scotts Flat Reservoir	Deer Creek Yuba	5	Upper Watershed Reservoirs
Silver Lake	Silver Fork American	5	Upper Watershed Reservoirs
Slab Creek Reservoir	South Fork American River	5	Upper Watershed Reservoirs
Sly Creek Reservoir	Lost Creek	5	Upper Watershed Reservoirs
Union Valley Reservoir	Silver Creek	5	Upper Watershed Reservoirs

Key: ab=above; bw=below; CVP=Central Valley Project; IFR=instream flow requirement; NOD=north of Delta; SOD=south of Delta; SWP=State Water Project; SWRCB=State Water Resources Control Boar

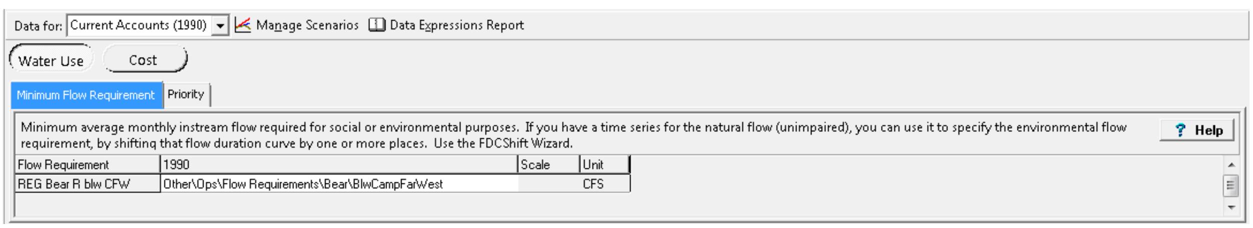
When demands sites or catchments are connected to more than one supply source, the order of withdrawal is determined by supply preferences. Similar to demand priorities, supply preferences are assigned a value between 1 and 99, with lower numbers indicating preferred water sources. The assignment of these preferences usually reflects some combination of economic, environmental, historic, legal, and political realities. In general, multiple water sources are present when the preferred water source is insufficient to satisfy all of an area's water demands. WEAP treats the additional sources as supplemental supplies and will draw from these sources only after it encounters a capacity constraint (expressed as either a maximum flow volume or a maximum percent of the demand) associated with the preferred water source. In general, SacWAM is set up such that surface water is given preference over pumping groundwater.

6.1.3 Flow Requirements



6.1.3.1 *Water Use*

Minimum Flow Requirement



In the upper watersheds, flow requirements are used to drive the simulation of water transfers via tunnels and canals. These flow requirements differ from regulatory requirements and are designated with an "OPS" in their name. Regulatory requirements have a "REG" in their name.

A *Minimum Flow Requirement* (MFR) has been specified for some rivers. Flow requirements that are regulatory in nature are named using the prefix "REG." REG parameters reference rules in the *Other\Ops* section of WEAP and are documented in Chapter 7.

A second type of flow requirement is used to drive simulated operations of upstream reservoirs, or diversions through tunnels, canals, and pipelines. These flow requirements, which are operational in nature, are designated using the prefix "OPS." In the upper watersheds, OPS flow requirements are typically set equal to the average monthly flows from 1970 to 2009. For more detail see **upper watershed diversion flows**.

A third type of flow requirement is the "SWRCB" type. These were added to SacWAM to allow model users to set and test new regulatory flow requirements where the flow requirement is specified as a fraction of the unimpaired flow. For more details on how to use the SWRCB-type flow requirements, see Section 9.3.

Priority

Priorities for flow requirements, demand sites and catchments, and reservoirs are discussed in Chapter 7 on Other Assumptions, Section 7.2.4.

6.1.3.2 *Cost*

The WEAP *Cost* feature for Flow Requirements is not used in SacWAM.

6.1.4 Reaches

6.1.4.1 *Inflows and Outflows*

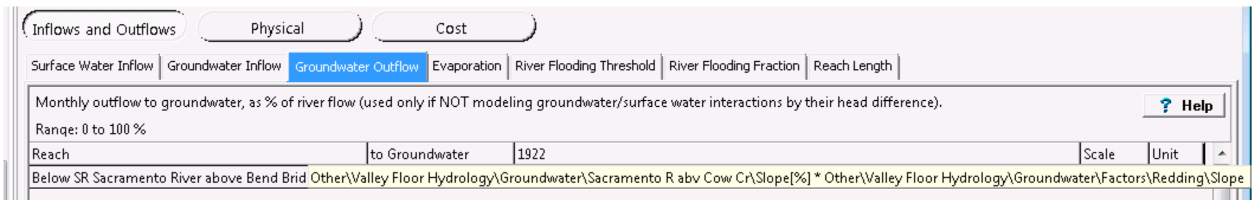
Surface Water Inflow

The WEAP *Surface Water Inflow* feature is not used in SacWAM.

Groundwater Inflow

The *Groundwater Inflow* feature is used to simulate surface water groundwater interactions.

Groundwater Outflow



The *Groundwater Outflow* feature is used to simulate surface water groundwater interactions.

Evaporation

The *Evaporation* WEAP feature is not used in SacWAM.

River Flooding Threshold

The *River Flooding Feature* WEAP feature is not used in SacWAM.

River Flooding Fraction

The *River Flooding Fraction* WEAP feature is not used in SacWAM.

Reach Length

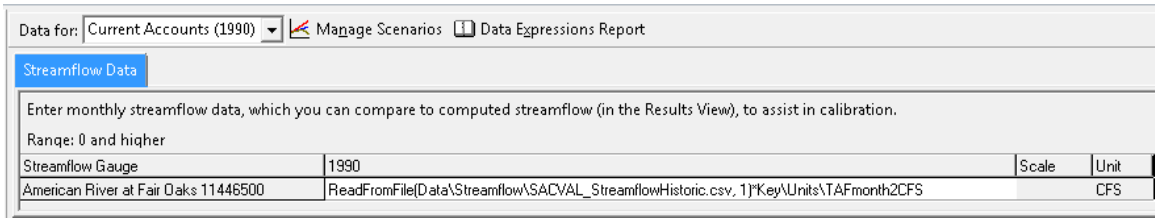
6.1.4.2 *Physical*

The *Physical* WEAP feature is not used in SacWAM.

6.1.4.3 *Cost*

The *Cost* WEAP feature is not used in SacWAM.

6.1.5 Streamflow Gauges



Streamflow gauges are used to provide comparisons between simulated and observed values of flow. In SacWAM, observed data are read from a SACVAL_StreamflowHistoric.csv file located in Data\Streamflow within the model area directory.

6.1.5.1 *Streamflow Data*

Streamflow gauge data are used in SacWAM to assess model performance. In some cases the streamflow gauge objects in the model represent computed full natural flows or estimates of unimpaired flows. To differentiate between actual observed flow data, full natural flows, and estimated unimpaired flows each gauge has been given a prefix of either HIS, FNF, or EST.

Historical

Historical streamflow data were obtained from the USGS Current Water Data for the Nation website (USGS, 2014), DWR's Water Data Library (DWR, 2014c), DWR's CDEC (DWR, 2014d) and by contacting DWR directly.

Historical streamflow data are saved in a csv file and contained in the SacWAM directory (Data\Streamflow\SACVAL_StreamflowHistoric.csv*)* with the exception of gauges without any infrastructure upstream, for which streamflow data are identical to inflow arc data (Table 6-6). For more information regarding streamflow data, refer to the **streamflow gauges**.

Table 6-6. SacWAM Streamflow Gauges and Corresponding Inflow Arcs

Streamflow gauge	Inflow arc
HIS Antelope Ck nr Red Bluff 11379000	I_ANT011
HIS Battle Creek nr Cottonwood 11376550	I_BTL006
HIS Bear Ck nr Millville	I_BCN010
HIS Big Chico Ck nr Chico 11384000	I_BCC014
HIS Clear Lake Inflows	I_CLRLK
HIS Cottonwood Ck nr Olinda 11375810	I_SCW008
HIS COW014	I_COW014
HIS Deer Ck nr Vina 11383500	I_DRC012
HIS Dry Creek	I_DSC035
HIS East Park Res Inflow	I_EPARK
HIS Elder Ck nr Paskenta 11379500	I_ELD027
HIS Farmington Res Inflow	I_LJC022
HIS Fordyce Res Inflow	I_FRDYC
HIS Indian Valley Res inflow	I_INDVL
HIS Jackson Meadows Res Inflow	I_JKSMD
HIS Lake Berryessa Inflow	I_BRYSA
HIS Little Dry Ck	I_LDC029
HIS Little Grass Valley Res Inflow	I_LGRSV
HIS Los Vaqueros Reservoir Inflow	I_LOSVQ
HIS Mill Ck nr Los Molinos 11381500	I_MLC006
HIS New Hogan Res Inflow	I_NHGAN
HIS NF Yuba bw Goodyears Bar 11413000	I_NFY029
HIS Paynes and Sevenmile Cks 11377500	I_PYN001
HIS SF Cottonwood Ck nr Olinda 11375870	I_SCW018
HIS Shasta Lake Inflow	I_SHSTA
HIS Thomes Ck at Paskenta 11382000	I_THM028
HIS Trinity Res Inflow	I_TRNTY

Key: bw=below; Ck=Creek; nr=near; Res=Reservoir.

Full Natural Flow

SacWAM gauges that represent full natural flows—the calculated flow that would be in the river without any upstream infrastructure—are designated with the prefix FNF and are equal to the sum of upstream inflow arc flows with exceptions noted in Table 6-7.

Table 6-7. Full Natural Flow Gauges Not Calculated as Sum of Upstream Inflow Arcs

Gauge	Data source
FNF American at Fair Oaks	California Data Exchange Center station AMF
FNF Camanche Res Inflow	I_CMCHE + FNF Mokelumne at Mokelumne Hill + I_PARDE
FNF Cosumnes at Michigan Bar	California Data Exchange Center station CSN
FNF Feather at Oroville	California Data Exchange Center station FTO
FNF Mokelumne at Mokelumne Hill	California Data Exchange Center station MKM and USGS 11394500
FNF Mokelumne at Pardee	FNF Mokelumne at Mokelumne Hill + I_PARDE
FNF Whiskeytown Res Inflow	I_CLR025

Key: FNF=full natural flow; Res=Reservoir.

Estimated

[22 stream gauge expressions look at SACVAL_StreamflowHistoric.csv or SACVAL_Headflows.csv to get EST values.]

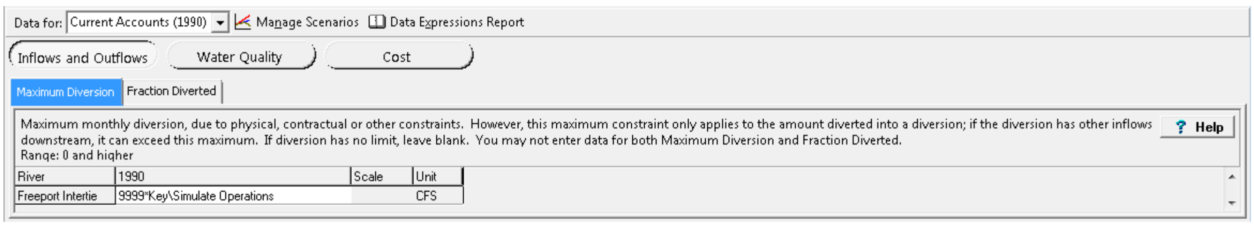
6.2 Diversion

Diversion arcs typically represent man-made conveyance facilities, including canals, pipelines, and hydropower penstocks. They are represented by orange arcs in the SacWAM schematic. In the WEAP data tree “Diversions” are aggregated with “Rivers.” However, some of the diversion properties differ from rivers.

In the upper watersheds, the operation of this infrastructure is achieved using flow requirements to demand monthly average values based on water years 1970-2009, similar to the approach used for reservoir storage. If in the future a more sophisticated representation of the operations rules is needed for these infrastructure, they can be modified

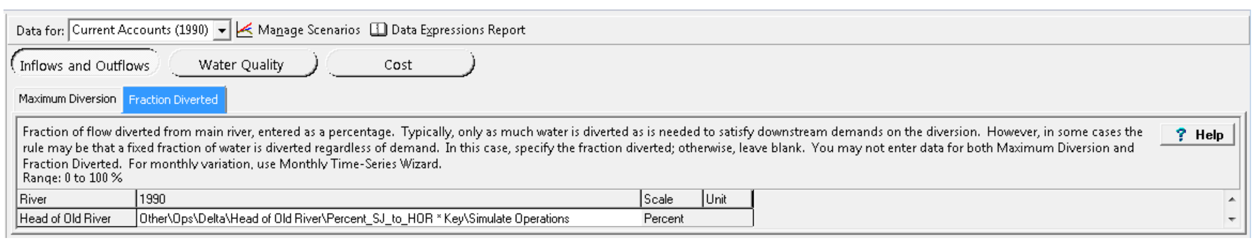
6.2.1 Inflows and Outflows

6.2.1.1 *Maximum Diversion*



The maximum diversion parameter is used to limit the flow through a diversion arc. In SacWAM this parameter is used to restrict flow to a canal or pipeline’s physical limit. See **maximum diversions** for more information.

6.2.1.2 *Fraction Diverted*



No values were entered except for Other\Ops\Delta\Head of Old River\Percent_SJ_to_HOR * Key\Simulate Operations for Head of Old River.

6.2.2 Water Quality

The WEAP *Water Quality* feature for diversions is not used.

6.2.3 Cost

The WEAP *Cost* feature for diversions is not used.

6.2.4 Reaches

6.2.4.1 *Inflows and Outflows*

Surface Water Inflow

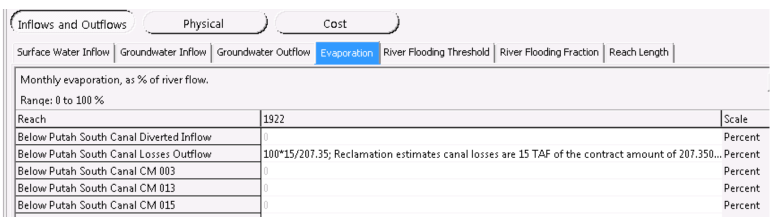
This parameter is meant to reflect monthly values of surface water inflow beyond that from catchments or tributaries. The following inflow reaches use headflow values when Simulate Hydrology is turned off (See Section 9.4).

- Below I_ALMMW
- BelowI_BTVLY Headflow
- BelowI_DAVIS Headflow

Groundwater Inflow and Groundwater Outflow

Some *Reaches* include expressions for groundwater inflow and outflow. These parameters are controlled through *Other Assumptions* and explained in Section 7.3.4.

Evaporation



Reclamation estimates canal losses by evaporation are 15 TAF of the contract amount of 207.350 TAF. This amounts to over 7%. This is the only Reach in the model for which an evaporation value is entered.

6.2.4.2 *Maximum Diversion*

In the upper watersheds the tunnel and canals are constrained to have a flow no larger than the average monthly flow. These expressions for these parameters are in **maximum diversions**. The values are found in **upper watershed diversion flows**.

6.2.4.3 *Fraction Diverted*

This parameter was not used in the upper watersheds.

6.3 Groundwater

SacWAM includes ten groundwater basins, each basin represented using a groundwater object on the WEAP schematic. Inflows and outflows to and from the groundwater basins include deep percolation from natural, agricultural, and refuge areas represented by the demand unit catchment objects, return flows from urban demand sites, seepage losses on surface water distribution systems represented by losses to groundwater on transmission links and groundwater pumping to meet demands in the catchments and demand sites. The groundwater nodes also interact with the stream network through the *Groundwater Inflow* and *Groundwater Outflow* parameters on stream reaches. Details of the groundwater simulation are presented in Section 3.3.

6.3.1.1 *Deep Percolation*

In order to simulate deep percolation from irrigation and rainfall, an analysis was conducted to determine which groundwater basin receives recharge from each DU. The aggregated **groundwater basins** were intersected with the SacWAM DUs to produce the **groundwater basin intersection** shapefile. This intersection determined the percentage of each DU within one or more groundwater basins. The post-intersection processing is documented in the **gw basins spreadsheet**.

The information in the groundwater basin intersection shapefile was used to specify the destination of infiltration links (dashed blue line) from catchments and return flow links (solid red line) from urban demand demand sites. If the DU overlaid multiple groundwater basins, the relative proportions determined by the the spatial intersection described above were used to disaggregate the flows. A listing of each agricultural, agricultural, urban, and refuge DU and their respective links to groundwater basins is provided in Table 6-8,

Table 6-9, and Table 6-10.

Where the percentage of a DU that lies within a groundwater basin is less than or equal to 10%, the infiltration or runoff link is not represented on the schematic and proportions were recalculated with the groundwater basin portions less than or equal to 10% omitted from the total area.

6.3.1.1 *Groundwater Pumping*

Similar to deep percolation, the information in the **groundwater basin intersection** shapefile was used to determine the sources of groundwater for agricultural catchments and urban demand nodes Table 6-8, Table 6-9, and Table 6-10). Agricultural and refuge DUs all have at least one groundwater source in SacWAM. Urban DUs are either supplied entirely by groundwater, or conjunctively use surface water and groundwater.

For all DUs, the minimum and maximum amount of groundwater pumping were constrained as follows. Additional details regarding the parameter values are provided in Chapter 4 and Chapter 6.

The minimum amount of groundwater pumping for a DU is set by constraining the maximum percentage of the demand that can be met by surface water. This constraint was calculated based on an analysis of the areal extent of surface water delivery infrastructure. For instance, if 60% of a DU's cropped area overlaps a surface water delivery service area then the maximum percentage of the demand that can be met by surface water was set to 60% which translates into a minimum groundwater pumping constraint of 40%. This constraint was set in the *Maximum Flow Percent of Demand* parameter (see below) for the transmission link that connects a catchment or demand site to a surface water source. In the cases where a DU has more than one surface supply, a UDC was created that restricted the total surface water supply to a fraction of the total water requirement. The fraction is calculated using 1-*Minimum Groundwater Pumping Factor.* For more information see Section 8.13.

The maximum amount of groundwater pumping is specified using the *Maximum Flow Percent of Demand* parameter on transmission links that connect catchments and demand sites to ground water sources. These parameter values were derived by analysis of county land use surveys (DWR, 1994a-b, 1995a-b, 1996, 1997b, 1998a-c, 1999a-b, 2000a).

Table 6-8. Deep Percolation Destinations and Groundwater Sources for Agricultural Demand Units

Demand Unit	Deep Percolation to Groundwater Basin(s)	Groundwater Source(s)
A_02_NA	Redding (100%)	Redding (100%)
A_02_PA	Redding (100%)	Redding (100%)
A_02_SA	Redding (100%)	Redding (100%)
A_03_NA	Redding (100%)	Redding (100%)
A_03_PA	Redding (100%)	Redding (100%)
A_03_SA	Redding (100%)	Redding (100%)
A_04_06_NA	Red Bluff Corning (100%)	Red Bluff Corning (100%)
A_04_06_PA1	Red Bluff Corning (100%)	Red Bluff Corning (100%)
A_04_06_PA2	Red Bluff Corning (100%)	Red Bluff Corning (100%)
A_04_06_PA3	Red Bluff Corning (35%); Colusa (65%)	Red Bluff Corning (35%); Colusa (65%)
A_05_NA	Red Bluff Corning (100%)	Red Bluff Corning (100%)
A_07_NA	Colusa (100%)	Colusa (100%)
A_07_PA	Colusa (100%)	Colusa (100%)
A_08_NA	Red Bluff Corning (14%); Colusa (86%)	Red Bluff Corning (14%); Colusa (86%)
A_08_PA	Colusa (100%)	Colusa (100%)

A_08_SA1	Colusa (100%)	Colusa (100%)
A_08_SA2	Colusa (100%)	Colusa (100%)
A_08_SA3	Colusa (100%)	Colusa (100%)
A_09_NA	Butte (100%)	Butte (100%)
A_09_SA1	Butte (100%)	Butte (100%)
A_09_SA2	Butte (100%)	Butte (100%)
A_10_NA	Butte (100%)	Butte (100%)
A_11_NA	Sutter Yuba (15%); Butte (85%)	Sutter Yuba (15%); Butte (85%)
A_11_SA1	Butte (100%)	Butte (100%)
A_11_SA2	Butte (100%)	Butte (100%)
A_11_SA3	Butte (100%)	Butte (100%)
A_11_SA4	Sutter Yuba (100%)	Sutter Yuba (100%)
A_12_13_NA	Sutter Yuba (100%)	Sutter Yuba (100%)
A_12_13_SA	Sutter Yuba (100%)	Sutter Yuba (100%)
A_14_15N_NA1	Sutter Yuba (100%)	Sutter Yuba (100%)
A_14_15N_NA2	Sutter Yuba (100%)	Sutter Yuba (100%)
A_14_15N_NA3	Sutter Yuba (100%)	Sutter Yuba (100%)
A_14_15N_SA	Sutter Yuba (87%); Butte (13%)	Sutter Yuba (87%); Butte (13%)
A_15S_NA	Sutter Yuba (100%)	Sutter Yuba (100%)
A_15S_SA	Sutter Yuba (100%)	Sutter Yuba (100%)
A_16_NA	Sutter Yuba (100%)	Sutter Yuba (100%)
A_16_PA	Sutter Yuba (100%)	Sutter Yuba (100%)
A_16_SA	Sutter Yuba (100%)	Sutter Yuba (100%)
A_17_NA	Sutter Yuba (50%); Butte (50%)	Sutter Yuba (50%); Butte (50%)
A_17_SA	Sutter Yuba (100%)	Sutter Yuba (100%)
A_18_19_NA	Sutter Yuba (100%)	Sutter Yuba (100%)
A_18_19_SA	Sutter Yuba (100%)	Sutter Yuba (100%)
A_20_25_NA1	Yolo Solano (81%); Colusa (19%)	Yolo Solano (81%); Colusa (19%)
A_20_25_NA2	Yolo Solano (100%)	Yolo Solano (100%)
A_20_25_PA	Yolo Solano (100%)	Yolo Solano (100%)
A_21_NA	Yolo Solano (39%); Colusa (61%)	Yolo Solano (39%); Colusa (61%)
A_21_PA	Yolo Solano (38%); Colusa (62%)	Yolo Solano (38%); Colusa (62%)
A_21_SA	Yolo Solano (81%); Colusa (19%)	Yolo Solano (81%); Colusa (19%)
A_22_NA	American (100%)	American (100%)
A_22_SA1	American (100%)	American (100%)
A_22_SA2	American (100%)	American (100%)
A_23_NA	American (100%)	American (100%)
A_24_NA1	American (100%)	American (100%)
A_24_NA2	American (100%)	American (100%)

Table 6-8. Deep Percolation Destinations and Groundwater Sources for Agricultural Demand Units cont.

Demand Unit	Deep Percolation to Groundwater Basin(s)	Groundwater Source(s)
A_24_NA3	American (100%)	American (100%)
A_26_NA	American (100%)	American (100%)
A_50_NA1	Delta (100%)	Delta (100%)
A_50_NA2	Delta (100%)	Delta (100%)
A_50_NA3	Delta (100%)	Delta (100%)
A_50_NA4	Delta (100%)	Delta (100%)
A_50_NA5	Delta (100%)	Delta (100%)
A_50_NA6	Delta (100%)	Delta (100%)
A_50_NA7	Delta (100%)	Delta (100%)
A_60N_NA1	Cosumnes (100%)	Cosumnes (100%)
A_60N_NA2	Cosumnes (72%); American (28%)	Cosumnes (72%); American (28%)
A_60N_NA3	Eastern San Joaquin (56%); Cosumnes (44%)	Eastern San Joaquin (56%); Cosumnes (44%)
A_60N_NA4	Eastern San Joaquin (100%)	Eastern San Joaquin (100%)
A_60N_NA5	Eastern San Joaquin (24%); Cosumnes (76%)	Eastern San Joaquin (24%); Cosumnes (76%)
A_60S_NA	Eastern San Joaquin (100%)	Eastern San Joaquin (100%)
A_60S_PA	Eastern San Joaquin (100%)	Eastern San Joaquin (100%)
A_61N_PA	Eastern San Joaquin (100%)	Eastern San Joaquin (100%)
A_61N_NA1	Eastern San Joaquin (100%)	Eastern San Joaquin (100%)
A_61N_NA2	Eastern San Joaquin (100%)	Eastern San Joaquin (100%)
A_61N_NA3	Eastern San Joaquin (100%)	Eastern San Joaquin (100%)

Table 6-9. Deep Percolation Destination and Groundwater Sources for Urban Demand Units

Demand Unit	Return Deep Percolation to Groundwater Basin(s)[10]	Groundwater Source(s)
U_02_NU	Redding (100%)	Redding (100%)
U_02_PU	None	None
U_02_SU	None	Redding (100%)
U_03_NU	Red Bluff Corning (100%)	Red Bluff Corning (100%)
U_03_PU	None	Redding (100%)
U_03_SU	None	Redding (100%)
U_04_06_NU	Red Bluff Corning (79%), Colusa (21%)	Red Bluff Corning (79%), Colusa (21%)
U_05_NU	Red Bluff Corning (100%)	Red Bluff Corning (100%)
U_07_NU	Colusa (100%)	Colusa (100%)
U_08_NU	Red Bluff Corning (12%), Colusa (88%)	Red Bluff Corning (12%), Colusa (88%)
U_09_NU	Butte (100%)	Butte (100%)
U_10_NU1	None	Red Bluff Corning (62%); Butte (38%)
U_10_NU2	Butte (100%)	Butte (100%)
U_11_NU1	None	None
U_11_NU2	Butte (100%)	Butte (100%)
U_12_13_NU1	None	Sutter Yuba (100%)
U_12_13_NU2	Sutter Yuba (100%)	Sutter Yuba (100%)
U_14_15N_NU	None	None
U_15S_NU	None	Sutter Yuba (100%)
U_16_NU	Sutter Yuba (100%)	Sutter Yuba (100%)
U_16_PU	None	Sutter Yuba (100%)
U_17_NU	Sutter Yuba (100%)	Sutter Yuba (100%)
U_18_19_NU	Sutter Yuba (100%)	Sutter Yuba (100%)
U_20_25_NU	None	None
U_20_25_PU	None	Yolo Solano (100%)
U_21_NU	Sutter Yuba (13%); Colusa (87%)	Sutter Yuba (13%); Colusa (87%)
U_21_PU	None	None
U_22_NU	American (100%)	American (100%)
U_23_NU	American (100%)	American (100%)
U_24_NU1	None	American (100%)
U_24_NU2	None	American (100%)
U_26_NU1	None	American (100%)
U_26_NU2	None	American (100%)
U_26_NU3	None	American (100%)
U_26_NU4	None	American (100%)
U_26_NU5	None	American (100%)
U_26_NU6	American (100%)	None
U_26_PU1	None	American (100%)
U_26_PU2	None	American (100%)
U_26_PU3	None	American (100%)
U_26_PU4	None	American (100%)
U_26_PU5	None	American (100%)
U_60N_NU1	None	Eastern San Joaquin (61%), Cosumnes (39%)
U_60N_NU2	American (84%), Cosumnes (16%)	None
U_60N_PU	Cosumnes (100%)	None

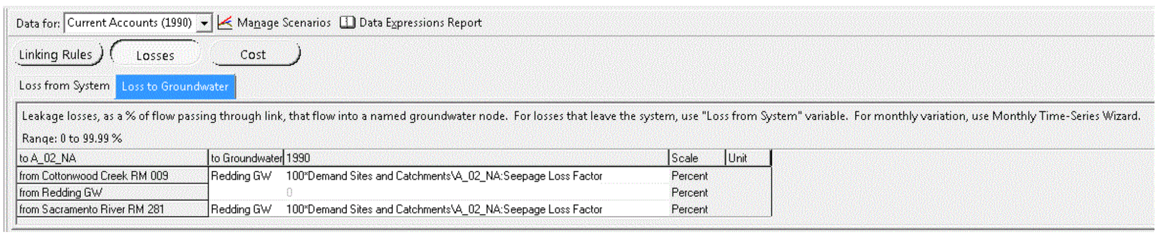
[10] Unlike agricultural and refuge lands which are represented by a single catchment object, urban areas are represented by both a catchment and demand site object. Consequently, an urban DU can have a return flow to a groundwater basin(s) from the demand site in addition to runoff from the catchment object.

Demand Unit	Return Deep Percolation to Groundwater Basin(s)[10]	Groundwater Source(s)
U_60S_NU1	None	Eastern San Joaquin (100%)
U_60S_NU2	Eastern San Joaquin (100%)	Eastern San Joaquin (100%)
U_61N_NU1	Eastern San Joaquin (100%)	Eastern San Joaquin (100%)
U_61N_NU2	Eastern San Joaquin (100%)	Eastern San Joaquin (100%)

Table 6-10. Groundwater Sources and Runoff for Refuge Demand Units

Demand Unit	Runoff Deep Percolation to Groundwater Basin(s)	Groundwater Source(s)
R_08_PR	Colusa (100%)	Colusa (100%)
R_09_PR	Butte (100%)	Butte (100%)
R_11_PR	Butte (100%)	Butte (100%)
R_17_NR	Butte (100%)	Butte (100%)
R_17_PR1	Butte (100%)	Butte (100%)
R_17_PR2	Sutter Yuba (100%)	Sutter Yuba (100%)

6.3.1.2 *Seepage Loss to Groundwater*



$$Loss\ to\ Groundwater\ (\%) = f_{sp}\ *\ 100$$

The *Loss to Groundwater* parameter is specified on each transmission link (the *Supply and Resources\Transmission Link\Demand Unit\Loss to Groundwater* branch in the data tree) that connects a catchment or demand site to a surface water source. As indicated in the above equation, *Loss to Groundwater* is defined as the *Seepage Loss Factor* indicated on the DU level multiplied by 100 to obtain a percentage (see 4.4.2.1 - Seepage Loss Factor for more detail about how *Seepage Loss Factor* values were determined). As shown above, in addition to the percentage of transmission flow lost to groundwater, the receiving groundwater basin must also be specified. To determine which groundwater basin a surface transmission link loses water to, the following rules were implemented:

- If a DU overlies one groundwater basin as determined by the **groundwater basin intersection**, that groundwater basin is specified as the basin to which the transmission link loses water.
- If a DU overlies two or more groundwater basins as determined by the **groundwater basin intersection** and has one surface water transmission link, it was assumed the loss to groundwater infiltrates to the groundwater basin that underlies the larger proportion of the DU.
- If a DU overlies two or more groundwater basins as determined by the **groundwater basin intersection** and has multiple surface water transmission links, the loss to groundwater was split between the groundwater basins where the groundwater basin comprises 35% or more of the DU.

6.3.1.3 *Stream – Aquifer Interaction*

Interaction between streams and aquifers is simulated in the SacWAM using factors derived by SWRCB staff from the C2VSim groundwater model. These loss and gain factors were derived from a C2VSim model run in which the land use was kept constant at the level of development for water year 2009, the most recent year available in C2VSim. The model run consisted of an ensemble of results based on multiple 5 year runs in which the initial conditions were reset every 5 years to the state of the groundwater system simulated by the historical C2VSim model run for the end of water year 2009. The model was run for 88 years in this manner. The idea behind this approach is that future management of the Valley's groundwater will not result in long-term trends of storage loss or gain, therefore the groundwater heads were reset every 5 years to match the recent historical past. From the ensemble run, monthly stream flow and seepage to groundwater were recorded for each C2VSim stream reach. These values were regressed and the resulting slope and intercept of the linear regression expression were used to specify the Groundwater Inflow and Groundwater Outflow on stream reaches that were designated to have stream-aquifer interactions. In general, the most downstream SacWAM reach on a corresponding C2VSim reach was selected to represent the stream-aquifer interactions for the entire C2VSim reach. For example, on Cow Creek, which is a single stream reach in C2VSim, the stream-aquifer interactions in SacWAM were set to occur on the reach called "Below SR Cow Creek," which is the last stream reach before the confluence with the Sacramento River.

The parameters used to characterize the stream-aquifer interactions are provided in Table 6-11. The slope was entered into the *Groundwater Outflow* parameter as a percent and represents the percentage of the streamflow that flows to the aquifer. The intercept was entered into the *Groundwater Inflow* parameter and represents the flow from the aquifer to the stream reach. This information is provided in the **groundwater functions** spreadsheet. During calibration of the valley floor hydrology these parameters were further adjusted to mimic the overall behavior of C2VSim (see Appendix B).

Table 6-11. Stream-Aquifer Parameters Derived from C2VSim

C2VSim Reach #	SacWAM Reach Name	Description	Slope (%)	Intercept (cfs)	Basin	Slope Adjustment Factor
25	Below I_CLV026 Inflow	Calaveras R	18.07	0.00	Eastern San Joaquin	1.7
27	Below Mokelumne River RM 050	Mokelumne R	14.00	0.00	Cosumnes	1.0
27	Below Mokelumne River RM 035	Mokelumne R	14.00	0.00	Eastern San Joaquin	1.0
29	Below SR Cosumnes River	Cosumnes R	0.36	0.00	American	
29	Below I_DEE023 Inflow	Cosumnes R	0.36	0.00	Cosumnes	1.0
32	Below SR Sacramento River above Bend Bridge Gauge	Sacramento R abv Cow Ck	0.66	62.65	Redding	1.4
33	Below SR Cow Creek	Cow Ck	3.17	10.95	Redding	1.4
34	Below Bear Creek Inflow	Sacramento R blw Cow Ck	0.22	46.60	Redding	1.4
35	Below SR Cottonwood Creek	Cottonwood Ck	1.22	1.06	Redding	0.6
36	Below Battle Creek RM 006	Battle Ck	3.44	29.50	Redding	1.0
37	Below SWRCB Sac AB Bend Bridge	Sacramento R blw Battle Ck	0.18	55.18	Red Bluff Corning	1.4
37	Below Battle Creek Inflow to Sacramento RM 269	Sacramento R blw Battle Ck	0.18	55.18	Redding	1.4
38	Below I_PYN001 Inflow	Paynes Ck	1.76	17.76	Red Bluff Corning	1.0
39	Below Sacramento River RM 240	Sacramento R blw Paynes Ck	0.15	77.33	Red Bluff Corning	1.4
40	Below SR Antelope Creek	Antelope Ck	1.43	22.29	Red Bluff Corning	1.0
41	Below Catchment Inflow Node 94	Sacramento R blw Antelope Ck	0.11	25.50	Red Bluff Corning	1.4
42	Below I_ELD027 Inflow	Elder Ck	9.42	14.27	Red Bluff Corning	1.0
43	Below Mill Creek RM 006	Mill Ck	1.87	8.89	Red Bluff Corning	1.0
44	Below McClure Creek Inflow to Sacramento River RM 225	Sacramento R blw Mill Ck	0.15	29.52	Red Bluff Corning	1.4
45	Below SR Thomes Creek	Thomes Ck	9.40	4.41	Red Bluff Corning	0.7
46	Below Catchment Inflow Node 99	Sacramento R blw Thomes Ck	0.14	22.96	Red Bluff Corning	1.4
47	Below Deer Creek RM 005	Deer Ck	1.45	3.33	Red Bluff Corning	1.0
48	Below Catchment Inflow Node 104	Sacramento R blw Deer Ck	0.29	37.20	Red Bluff Corning	1.4
49	Below Constant Head Orifice Outflow	Stony Ck	6.09	0.00	Colusa	2.8
49	Below SR Stony Creek	Stony Ck	6.09	0.00	Red Bluff Corning	2.8
50	Below Catchment Inflow Node 106	Big Chico Ck	0.31	0.02	Butte	1.0
50	Below Catchment Inflow Node 105	Big Chico Ck	0.31	0.02	Red Bluff Corning	1.0
51	Below Sacramento River RM 159	Sacramento R blw Big Chico Ck	2.08	232.61	Butte	0.9
51	Below SR Sacramento River above Butte City Gauge	Sacramento R blw Big Chico Ck	2.08	232.61	Colusa	1.4
52	Below A_11_SA3 Runoff	Butte Ck	14.75	0.00	Butte	0.9
53	Below OPS Navigation Control Point	Sacramento R abv CBD	0.96	72.76	Colusa	1.4
53	Below Sacramento River RM 109	Sacramento R abv CBD	0.96	72.76	Sutter Yuba	1.4
55	Below Colusa Basin Drainage Canal CM 049	Upr Colusa Basin Drain	5.84	127.19	Colusa	1.0
56	Below SR Colusa Basin Drain Above Outfall Gates Gauge	Lwr Colusa Basin Drain	14.91	272.87	Colusa	1.0
57	Below Sutter Bypass Floodflow Inflow	Sacramento R blw CBD	0.31	14.54	Colusa	1.4
57	Below Sutter Bypass Inflow to Sacramento RM 085	Sacramento R blw CBD	0.31	14.54	Sutter Yuba	1.4

Table 6-11. Stream-Aquifer Parameters Derived from C2VSim cont.

C2VSim Reach #	SacWAM Reach Name	Description	Slope (%)	Intercept (cfs)	Basin	Slope Adjustment Factor
58	Below A_17_NA Runoff	Sutter Bypass	4.99	58.71	Sutter Yuba	0.55
59	Below Feather River RM 039	Feather R abv Yuba R	1.91	95.50	Butte	1.0
59	Below Feather River RM 045	Feather R abv Yuba R	1.91	95.50	Sutter Yuba	1.0
60	Below Yuba River RM 003	Yuba R	0.99	0.00	Sutter Yuba	1.0
61	Below Feather River RM 014	Feather R abv Bear R	2.15	53.36	Sutter Yuba	1.0
62	Below SR Bear River	Bear R	5.57	0.00	American	2.0
62	Below Dry and Hutchinson Creeks Inflow	Bear R	5.57	0.00	Sutter Yuba	2.0
64	Below REG Verona	Feather R blw Sutter Bypass	2.06	176.31	American	1.0
64	Below Feather River RM 007	Feather R blw Sutter Bypass	2.06	176.31	Sutter Yuba	1.0
65	Below Sacramento River RM 074	Sacramento R blw Feather R	1.01	0.00	American	1.4
65	Below Natomas East Main Drain Inflow	Sacramento R blw Feather R	1.01	0.00	Yolo Solano	1.4
66	Below REG American IFR	American R	1.50	0.00	American	1.3
67	Below Georgiana Slough fr Sacramento River RM 029 Outflow	Sacramento R blw American R	0.62	0.00	Delta	1.4
68	Below Cache Creek RM 030	Cache Ck	32.11	2.95	Colusa	0.7
68	Below SR Cache Creek above Yolo Gauge	Cache Ck	32.11	2.95	Yolo Solano	0.7
69	Below REG Lower Putah Diversion Dam	Putah Ck	9.71	0.00	Yolo Solano	3.3

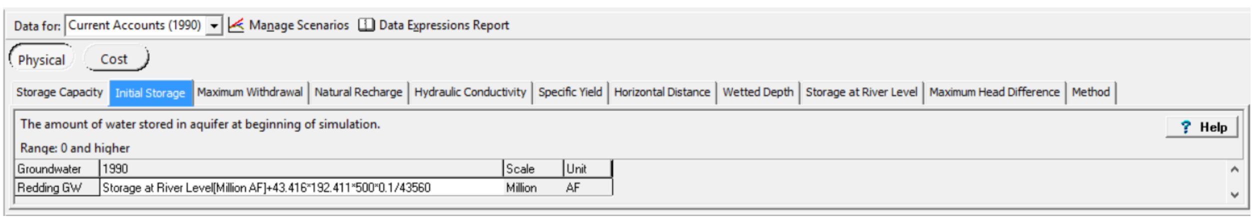
Key: abv=above, blw=below; CBD=Colusa Basin Drain; cfs=cubic feet per second; Ck=Creek; CM=Canal Mile; fr=from; R=River; RM=River Mile; SR=surface return.

6.3.2 Physical

6.3.2.1 *Storage Capacity*

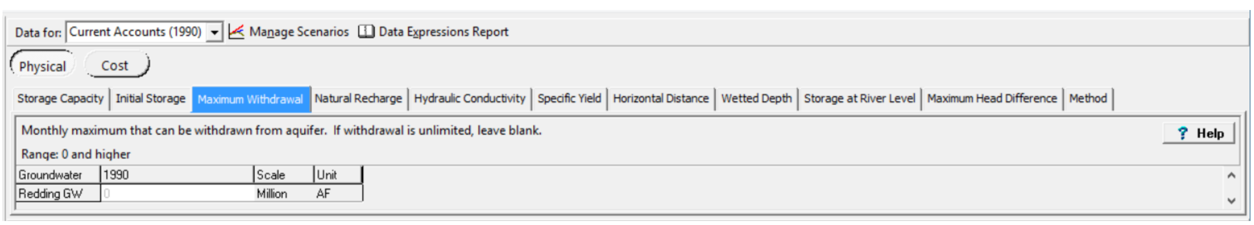
The storage capacity parameter is used to specify the total volume of available storage in a groundwater aquifer. In SacWAM, this parameter has been left blank which means the capacity is unlimited.

6.3.2.2 *Initial Storage*



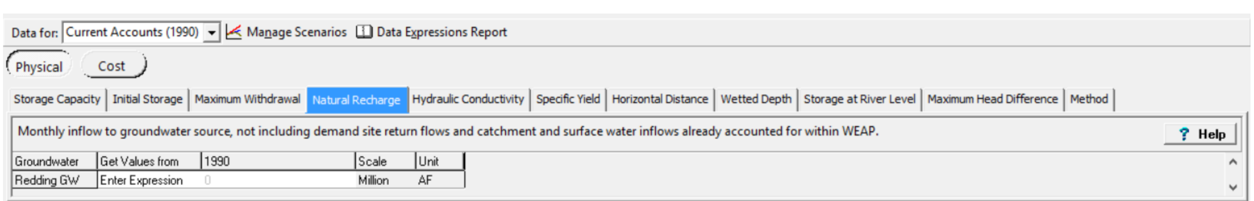
This parameter sets the initial storage in the aquifer. For all aquifers this value was arbitrarily set to 30 million AF.

6.3.2.3 *Maximum Withdrawal*



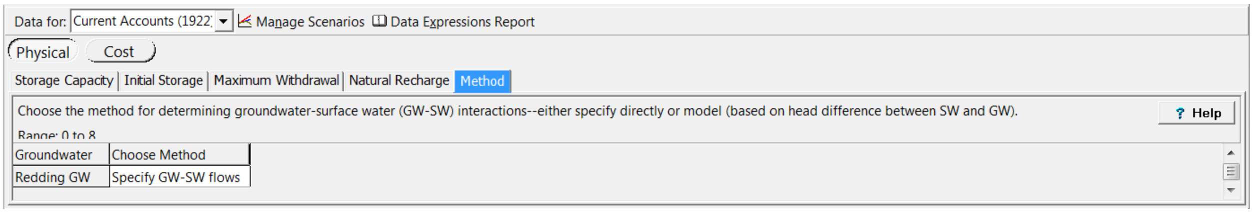
This parameter restricts the amount of water that can be withdrawn from the aquifer in a time step. In SacWAM this parameter was left blank making it unrestricted.

6.3.2.4 *Natural Recharge*



This parameter is used to specify recharge to the aquifer. This parameter is blank. In SacWAM aquifer recharge is simulated as deep percolation from catchments, return flows from demand sites, and seepage from transmission links.

6.3.2.5 *Method*



For each groundwater basin, the method for simulating stream-groundwater interaction is set to “Specify GW-SW flows.”

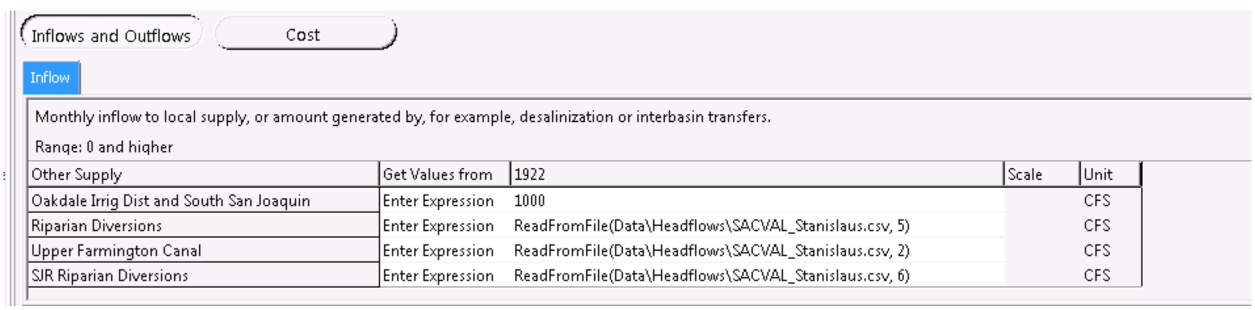
6.3.3 Cost

The *Cost* feature under *Groundwater* is not used in SacWAM.

6.4 Other Supply

The use of the ‘Other Supply’ object in SacWAM is limited to the San Joaquin Valley. It provides water to lands on the southern boundary of the model domain located between the Calaveras and Stanislaus rivers, east of the San Joaquin River. The Other Supply represents: (1) water that is diverted from the Stanislaus River and flows into the Calaveras watershed, and (2) water used by riparian diverters along the San Joaquin River that extract their water upstream from Vernalis. It is assumed that these supplies are sufficient to meet the water demands of the local water users.

6.4.1 Inflows and Outflows



The Other Supply inflow was set to 1,000 cubic feet per second (cfs) to ensure that there is sufficient water to meet Oakdale ID demands.

6.4.2 Cost

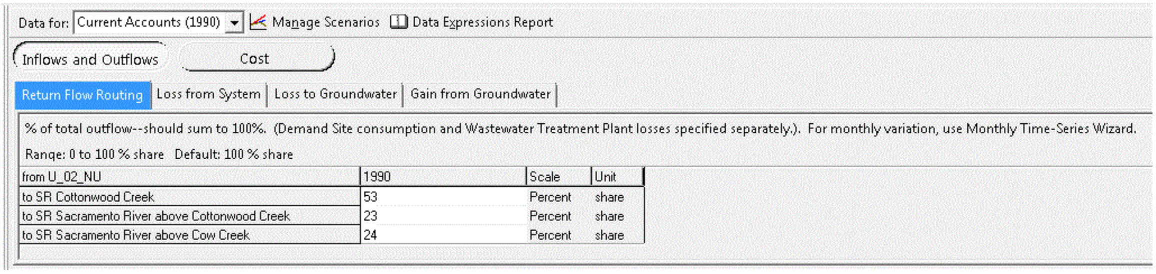
The *Cost* feature under *Other Supply* is not used in SacWAM.

6.5 Return Flows

6.5.1 Inflows and Outflows

6.5.1.1 *Return Flow Routing*

In addition to surface runoff fractions that are specified for urban catchments (dashed blue line in WEAP), return flow percentages from urban demand sites must be specified for return flow links (solid red line in WEAP). These are entered under the *Supply and Resources\Return Flows\Demand Site\Inflows and Outflows\Return Flow Routing* branch of SacWAM (below). Return flows were determined using the surface **returns intersection**, except where there are known WWTPs.



6.5.1.2 *Loss from System*

The *Loss from System* feature under Inflows and Outflows is not used in SacWAM.

6.5.1.3 *Loss to Groundwater*

The *Loss to Groundwater* feature under Inflows and Outflows is not used in SacWAM.

6.5.1.4 *Gain from Groundwater*

The *Gain from Groundwater* feature under Inflows and Outflows is not used in SacWAM.

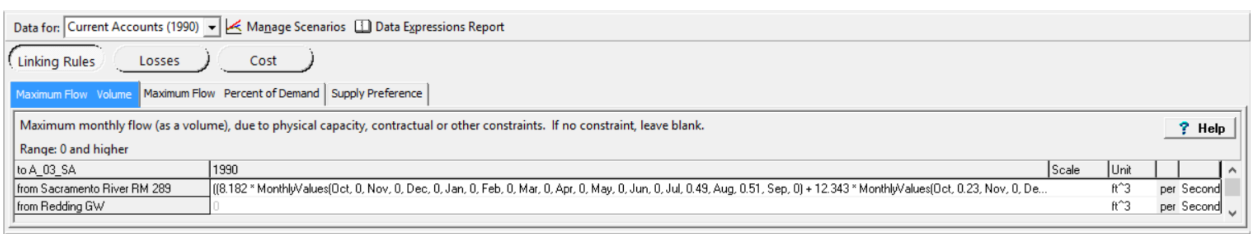
6.5.2 Cost

The *Cost* feature under *Return Flows* is not used in SacWAM.

6.6 Transmission Links

6.6.1 Linking Rules

6.6.1.1 *Maximum Flow Volume*



The **maximum flow volume** parameter is used to restrict the total volume of water that can flow through a transmission link. In SacWAM, this parameter is used to restrict flows according to water rights and contract limits. A sample expression is presented below for a CVP settlement contractor:

((8.182 * MonthlyValues(Oct, 0, Nov, 0, Dec, 0, Jan, 0, Feb, 0, Mar, 0, Apr, 0, May, 0, Jun, 0, Jul, 0.49, Aug, 0.51, Sep, 0)

+ 12.343 * MonthlyValues(Oct, 0.23, Nov, 0, Dec, 0, Jan, 0, Feb, 0, Mar, 0, Apr, 0.11, May, 0.14, Jun, 0.29, Jul, 0, Aug, 0, Sep, 0.23))

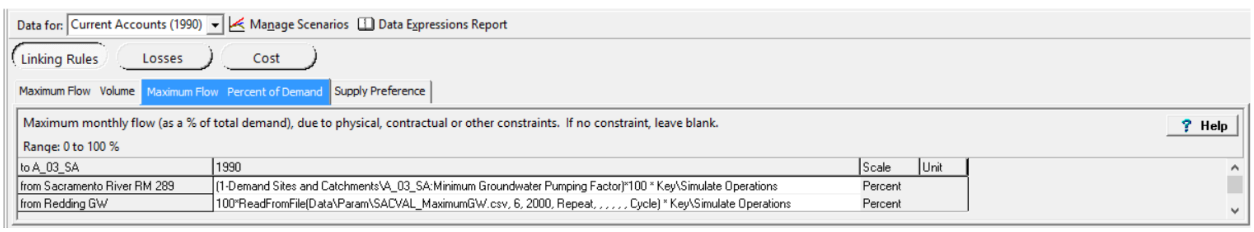
* *Key\Units\TAFmonth2CFS*

* *Other\Ops\CVP Allocations\Shasta_Crit*

+ 9999 * MonthlyValues(Oct, 0, Nov, 1, Dec, 1, Jan, 1, Feb, 1, Mar, 1, Apr, 0, May, 0, Jun, 0, Jul, 0, Aug, 0, Sep, 0))

In this expression, the first block of information contains the contract amount (8.182 TAF) for the critical months (July and August) multiplied by the monthly portion of the contract that can be diverted during the peak months. The second block of information contains the full contract amount for the non-peak months (12.343 TAF) for the non-peak months multiplied by the monthly portion of the contract that can be diverted during the non-peak months. In the actual contract, only the total April – October (8.182+12.343) and July and August (8.182) volumes are specified. In SacWAM, the monthly proportions are based on average monthly water demands. The third block is a unit conversion from TAF to cfs. The fourth block implements an allocation based on Shasta critical years. The fifth block allows diversions (up to the full water demand) from November to March, as water rights outside of the irrigation season specified in the CVP contracts have not currently been quantified for SacWAM.

6.6.1.2 *Maximum Flow Percent of Demand*

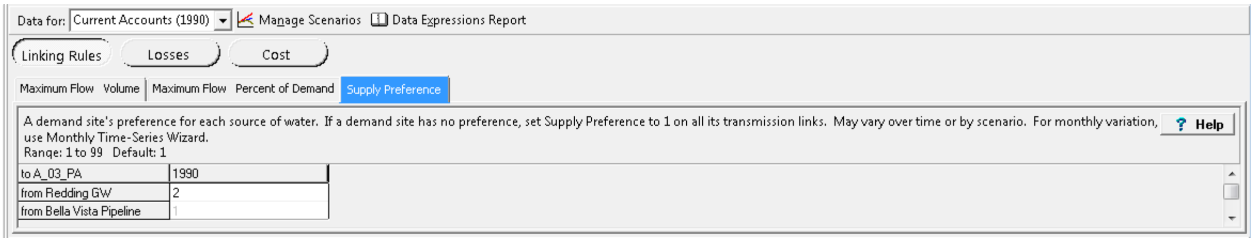


The **maximum flow percent of demand** is used to restrict the flow through a particular transmission link to a percent of the demand in the destination catchment or demand site. In SacWAM this parameter is used to implement various restrictions:

1. For transmission links that transport water from a groundwater source to a catchment or demand site, the maximum groundwater pumping fraction is entered in this parameter. These values were calculated by analysis of the county land use surveys (DWR, 1994a-b, 1995a-b, 1996, 1997b, 1998a-c, 1999a-b, 2000a) and determined by summing the total area in a DU that is served by groundwater only and groundwater and surface water.
2. For transmission links that transport water from surface water to agricultural catchments, the maximum percent of demand that can be met by surface water is defined as one minus the minimum groundwater pumping factor (see Minimum Groundwater Pumping Factor in Section 4.4).
3. For urban DU demand sites, this parameter is used to specify the maximum fraction of the demand that can be served by surface water. This forces a certain level of groundwater pumping representing capacity, operational constraints and other factors.
4. For demand sites outside of the valley floor, this parameter is used to restrict total deliveries if water allocations are not at 100%. For example this is utilized for demands south of the Delta.

All parameters in maximum flow percent of demand are multiplied by a factor called *Key\Simulate Operations*. This factor has a value of zero when the model is run in the unimpaired mode. This setting forces the model to have zero flow on the transmission links. For more details see Section 9.7.

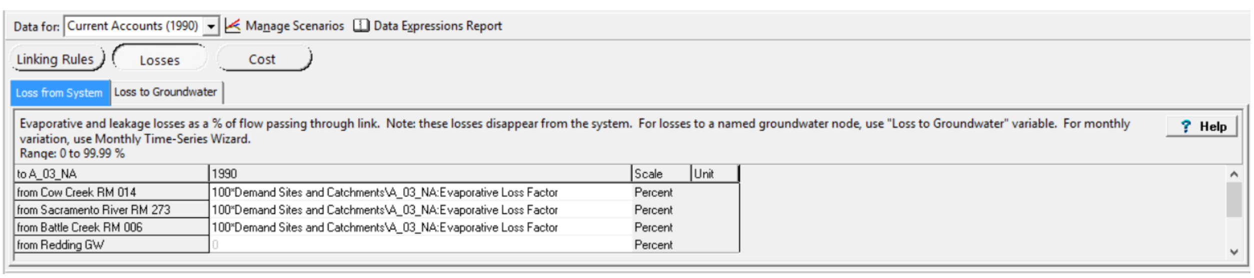
6.6.1.3 *Supply Preference*



Supply preference is used in determining the preference order for supplies in the case where a catchment or demand site has more than one supply. Most commonly this situation arises when a catchment or demand site is connected to a surface water supply and a groundwater supply. In SacWAM, the assumption is that surface water is used preferentially, and therefore given a preference value of "1", and ground water is the second preference with a preference value of "2". There are some cases in which a catchment has more than one surface water supply. In these cases the supply preferences were ranked based on information from water supply contracts.

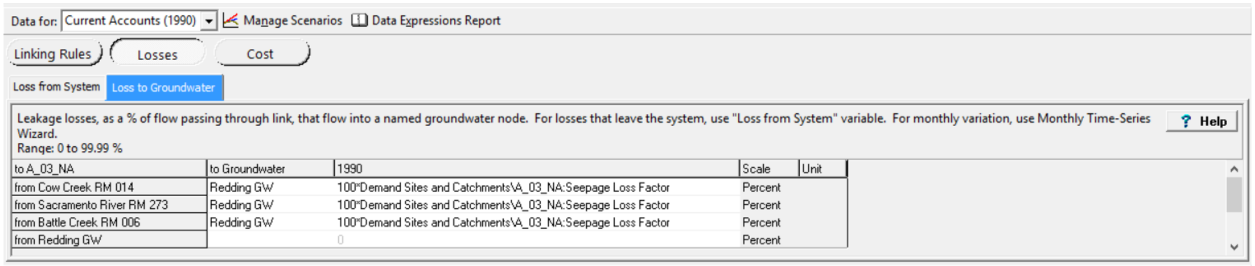
6.6.2 Losses

6.6.2.1 *Loss from System*



The *Loss from System* parameter specifies the fraction of water from the delivery system that is lost through evaporation. This parameter is specified using the *Evaporative Loss Factor* described in Section 4.4.

6.6.2.2 *Loss to Groundwater*



The *Loss to Groundwater* parameter specifies the fraction of water lost from delivery canals to the underlying groundwater through seepage. This parameter is specified using the Seepage Loss Factor described in Section 4.4.

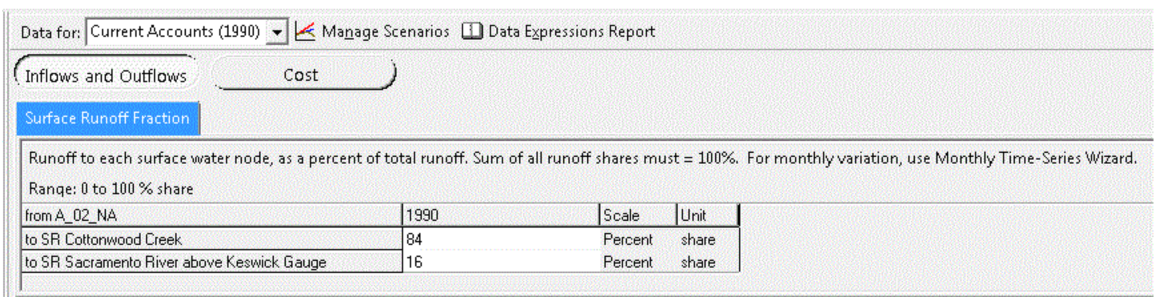
6.6.3 Cost

The *Cost* feature is not used in SacWAM.

6.7 Runoff and Infiltration

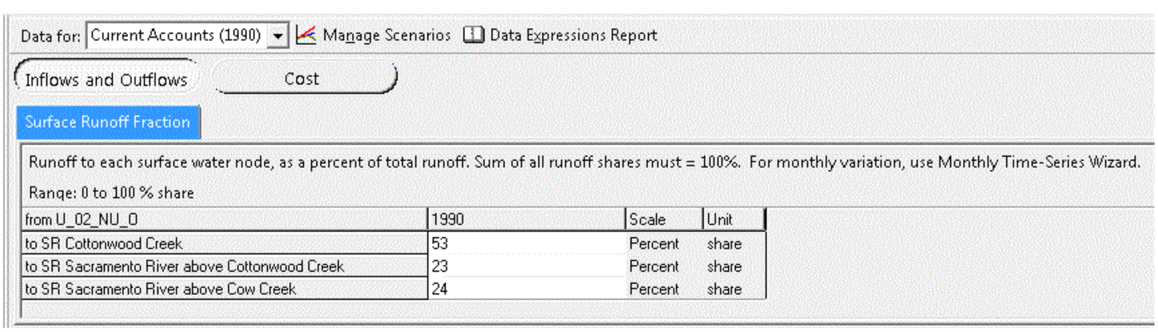
6.7.1 Inflows and Outflows

6.7.1.1 *Surface Runoff Fraction for Agricultural Catchments*



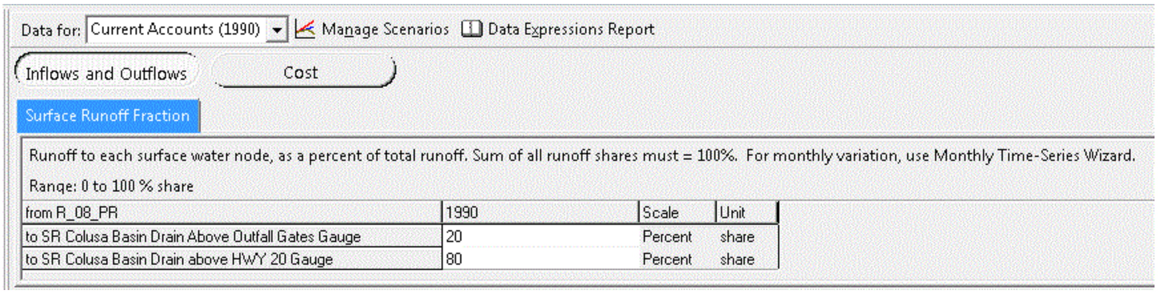
The surface runoff fraction is used to divide the runoff from a catchment object among different receiving surface water bodies. For agricultural catchments, these percentages can be found in Table 3-5 as described in Section 3.7.1.

6.7.1.2 *Surface Runoff Fraction for Urban Catchments*



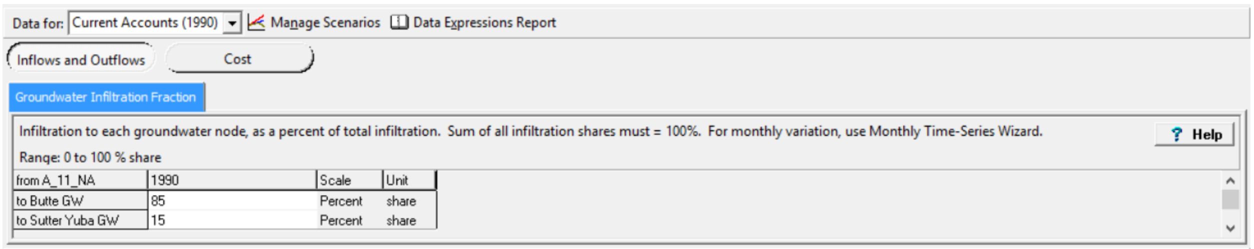
Surface runoff from urban catchments is divided using the values in Table 3-5 and Section 3.7.1.

6.7.1.3 *Surface Runoff from Refuge Catchments*



Surface runoff from refuge catchments is treated in a similar manner to that from agricultural catchments. Their specified percentages are listed in Table 3-5.

6.7.1.4 *Groundwater Infiltration Fraction*



The groundwater infiltration fraction specifies the fraction of the total deep percolation that flows to a particular receiving groundwater basin. This is used when a DU overlies more than one groundwater basin. The fractions entered in this parameter for agricultural, urban, and refuge DUs are described in Section 3.3 and provided in Table 6-8, Table 6-9, and Table 6-10.

6.7.2 Cost

The *Cost* features under *Runoff and Infiltration* are not used in SacWAM.

6.8 Operations Rules

The operations of reservoirs, tunnels, and canals in the upper watersheds have been kept relatively simple and do not fully reflect the complexity that exists in the operations of this infrastructure in the real system. This relatively simple approach was implemented as the operations of the upper watershed infrastructure is buffered by the large volume of storage available in the rim reservoirs. For now, the operations of the reservoirs and diversions (tunnels, canals) is set equal to the average monthly storage or flow.

6.8.1 Diversion Operations

The operations of reservoirs, tunnels, and canals in the upper watersheds have been set equal to the average monthly values based on water years 1970-2009. For more detail see Sections 6.1 and 6.2.

6.9 Data Directory

Table 6-12 provides location information in the 2014_WB_WEAP data directory for the datasets referenced in Chapter 6.

Table 6-12. File Location Information for Supply and Resources

Referenced Name	File Name	File Location*
maximum diversions	Maximum Diversion.xlsx	Rivers\Diversions
maximum flow percent of demand	Maximum Flow Percent of Demand.xlsx	Transmission_Links
maximum flow volume	Maximum Flow Volume.xlsx	Transmission_Links
reservoir storage capacity	SACVAL_SR_Riv_Res_Storage.xlsx	Rivers\Reservoirs
returns intersection	sac_val_returns_intersection.shp	GIS\Hydrology
streamflow gauges	SACVAL_SR_Riv_Streamflow_Gauges.xlsx	Rivers\Streamflow_Gauges
supply preference	Supply Preference.xlsx	Transmission_Links
upper watershed diversion flows	SACVAL_UpperWShed_DiversionFlows.xlsx	Rivers\Diversions
valley floor inflows	SACVAL_SR_Riv_Inflows.xlsx	Rivers\Historical_Inflows
volume elevation curve	SACVAL_SR_Riv_Res_Vol_Elev.xlsx	Rivers\Reservoirs

*Files located at Data\ Supply_and_Resources \... except for GIS files (GIS\...).

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Chapter 7 Other Assumptions

The "Other Assumptions" branch in WEAP holds parameters that are developed for a specific application. Other Assumptions allows for the development of model logic that is more complex than that directly supported by the interface screens related to the schematic objects.

The Other Assumptions in SacWAM are used to formulate operational constraints which include the following:

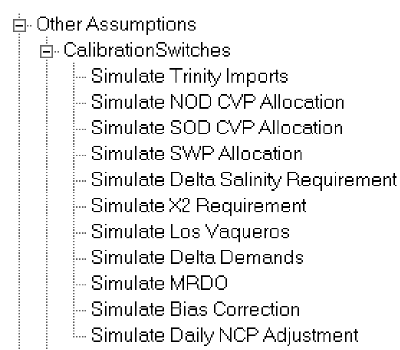
1. Project allocations
2. Project reservoir operations
3. Non-project reservoir operations
4. Flow requirements
5. Demand priorities
6. CVP/SWP water sharing agreements
7. Delta salinity and operations
8. Water supply forecasts and hydrologic indicies

This Chapter describes the Other Assumptions created for SacWAM, following the order of the WEAP data tree.

7.1 Calibration Switches

The Other Assumptions contain calibration switches that allow the user to force portions of the model to operate using predefined values. These switches were used to calibrate the model and will generally not be altered by future users of SacWAM. In general, "0" causes the model to use values derived from historical data or CalSim II; a value of "1" causes the model to use simulated values generated by SacWAM and catchments as defined in SacWAM. Switches are included for the following:

- Trinity imports
- North of Delta CVP allocation
- South of Delta CVP allocation
- SWP allocation
- Delta salinity requirement
- X2 requirement
- Los Vaqueros Reservoir
- Delta demands
- Minimum required Delta outflow



7.1.1 Simulate Trinity Imports

SacWAM offers two methods for setting Trinity River imports: the first sets these imports equal to a timeseries of historical Clear Creek Tunnel flows; the second uses import logic that assesses current storage levels in Trinity and Shasta to dynamically determine Trinity River imports. A "Simulate Trinity Imports" value of 1 indicates the decision to use the simulation logic, otherwise SacWAM will use historical import values. The import logic is discussed in Section 7.2.16.

7.1.2 Simulate NOD CVP Allocation

SacWAM includes a switch that allows the model user to fix CVP allocations north of the Delta to those simulated by CalSim II (as determined for the 2015 SWP Delivery Capability Report [DWR, 2015]). A "Simulate NOD CVP Allocation" value of 0 indicates SacWAM will use simulated values from CalSim II; a value of 1 indicates that SacWAM will use its own allocation logic.

7.1.3 Simulate SOD CVP Allocation

SacWAM includes a switch that allows the model user to fix CVP allocations south of the Delta to those simulated by CalSim II (2015 SWP Delivery Capability Report). A "Simulate SOD CVP Allocation" value of 0 indicates SacWAM will use simulated values from CalSim II; a value of 1 indicates that SacWAM will use its internal CVP allocation logic.

7.1.4 Simulate SWP Allocation

Similar to the CVP, SacWAM includes a switch that allows the model user to constrain SacWAM to SWP allocations from the CalSim II 2015 SWP Delivery Capability Report. A "Simulate SWP Allocation" value of 0 sets the model allocations equal to the CalSim II data; a value of 1 enables dynamic calculation in SacWAM.

7.1.5 Simulate Delta Salinity Requirement

Various switches allows the model user to constrain SacWAM to Delta salinity requirements from the CalSim II 2015 SWP Delivery Capability Report. For a "Simulate Delta Salinity Requirement" value of 0. The model uses CalSim II data to determine the net Delta outflow required for salinity control. A value of 1 enables dynamic calculation of the requirement using the ANN embedded in SacWAM. This is further discussed in section 7.2.6.3.

7.1.6 Simulate X2 Requirement

SacWAM includes an IFR object on net Delta outflow to simulate D-1641 and USFWS BiOP requirements for the X2 location. The "Simulate X2 Requirement" switch allows the model user to set this instream flow requirement to values determined by CalSim II for the 2015 SWP Delivery Capability Report. A "Simulate X2 Requirement" value of 0 sets SacWAM to use the CalSim II data; a value of 1 enables a dynamic calculation.

7.1.7 Simulate Delta Demands

The representation of in-Delta water use is discussed in section 3.8.3.14. The "Simulate Delta Demands" switch allows the user to choose between simulating Delta agricultural demands using the WEAP catchment objects or using a timeseries of Delta channel accretions and depletions based on the CalSim II 2015 SWP Reliability Report. A value of 0 sets SacWAM to use the CalSim II data, a value of 1 enables the SacWAM Delta catchment objects and dynamic calculation of Delta diversions and return flows.

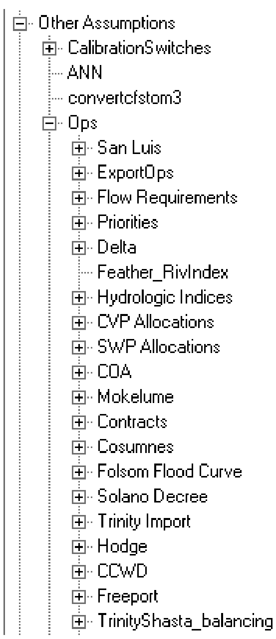
7.1.8 Simulate MRDO

The "MRDO" switch serves a purpose similar to Simulate X2 Requirement. When set to a value of 0, SacWAM uses CalSim II based values of D-1641 minimum required Delta outflow (MRDO) from the 2015

SWP Delivery Capability Report. A value of 1 enables dynamic calculation of this outflow requirement using SacWAM's internal rules.

7.1.9 Simulate Bias Correction

The "Simulate Bias Correction" switch allows the model user to activate inflow bias corrections implemented on the Sacramento River at Bend Bridge, Butte City, and Freeport. The corrections applied just upstream from the Bend Bridge gauge (RM 258) and Butte City gauge (RM 170) are based on a historical water balance of river inflows and outflows for the reach Shasta to Bend Bridge and the reach Bend Bridge to Butte City. Components of the flow balance include observed streamflow data, historical storage regulation and evaporation, historical trans-watershed imports, unimpaired inflows as used in SacWAM, historical stream diversions, and estimates of historical rainfall-runoff, historical irrigation return flows, and historical groundwater inflows. In the winter and spring, the residual or closure term in the flow balance is attributed to errors in the SacWAM unimpaired inflows. In many cases these inflows were derived from an extension of incomplete gauge data using statistical methods. Bias corrections are applied for the November – March period when unimpaired flows are the dominant component of the flow balance. Outside of these months, errors in the other flow balance terms are likely to be of similar magnitude to errors in in the SacWAM unimpaired inflows.



The correction at Freeport is different in nature. Its purpose is to give the model user the option of aligning the SacWAM hydrology to that of CalSim II. This option should be exercised when it is important to have consistency between the two models, e.g., in a comparison of simulated CVP/SWP operations. However, the model user should not infer any judgment regarding the relative accuracy of the two models. The correction is calculated as the difference between SacWAM and CalSim II combined simulated flows for the Sacramento River at Freeport and the Yolo Bypass at the Lisbon Weir, after removing the effects of upstream CVP/SWP storage regulation and Trinity imports. Thus, this correction adjusts for differences in model hydrology *and* for differences in model simulation of non-project tributaries.

7.1.10 Simulate Daily NCP Adjustment

The "Simulate Daily NCP Adjustment" switch allows the user to activate an adjustment to the Navigation Control Point (NCP) flow requirement for the Sacramento River below Wilkins Slough. This adjustment is used in CalSim II to determine the additional releases which are needed to meet the NCP requirement because of differences between monthly averaged inflows and daily flows. The switch is turned off by default in SacWAM, but can be activated for making comparisons to CalSim II.

7.2 Ops (Valley Floor Operations Rules)

Water management within the Sacramento Valley is subject to many regulatory standards. These standards are most commonly enacted as IFRs. These regulations influence the way that water managers (including, but not limited to, the CVP and SWP) allocate and distribute water throughout the valley. SacWAM includes logic that represents the regulations and the project operations.

Operation rules parameters appear in the WEAP tree under *Other Assumptions\Ops*. The expressions that define various rules are grouped under different categories (e.g. demand priorities, flow requirements, COA, etc.). These parameters are explained in more detail in the following sections.

7.2.1 San Luis Reservoir

San Luis Reservoir is an off-stream facility in the eastern part of the Diablo Range, west of the San Joaquin Valley. Water from the Delta is delivered to San Luis Reservoir via the California Aqueduct and DMC for temporary storage during the rainy season. During the dry season, this stored water is released for use by CVP and SWP water contractors south of the Delta. San Luis Reservoir also provides water to the Santa Clara Valley Water District and the San Benito County Water District. Water is delivered to these users through CVP's San Felipe Division on the west side of the reservoir.

In SacWAM, San Luis Reservoir is represented using two reservoir objects, one for the CVP pool and one for the SWP pool, as shown in Figure 7-17-1 This was done in order to more accurately simulate the complex operations of the reservoir. Each reservoir has two routes for receiving water from their respective supply canals. Water is first drawn into the reservoir to fill the reservoir to its "rule curve" subject to water availability in north-of-Delta reservoirs and restrictions on flows in the Delta. If there is excess water available in the Delta, additional water is drawn into the reservoir using priorities that differentiate between volumes above (conservation storage) and below (buffer storage) rule curve. This allows the reservoir to be filled using "excess" water that is most typically present in wetter months of winter ().

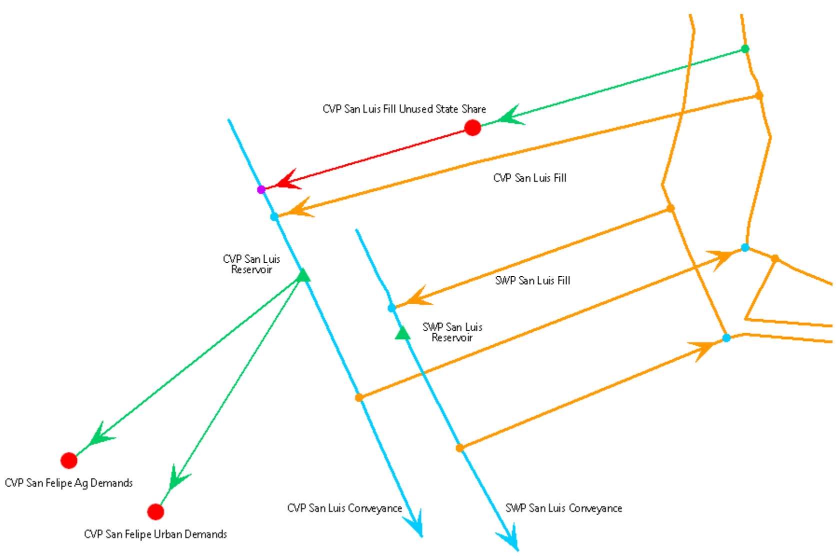


Figure 7-1. Schematic Representation of San Luis Reservoir

San Luis Reservoir is set up within SacWAM to fill during the fall and winter (October through March) and release during the spring and summer (April through September). This is accomplished by using a combination of priorities, target storages, and pumping limits. The priority for storage in San Luis

Reservoir is set such that water is pumped into the reservoir only after all other demands (agricultural, urban, and environmental) have been met, including meeting target storage for CVP/SWP reservoirs north of the Delta. The target storage for San Luis Reservoir is set to fill the reservoir from its low point—generally at the end of August—to its maximum capacity (2.04 million acre-feet, or MAF) by the end of March. Target storages defined by the rule curves define the desired volume of water to be released from north-of-Delta reservoirs to be pumped into San Luis.

There are separate parameters for CVP and SWP operations, which are identical to the parameters used in the CalSim II model. These parameters are explained in the following sections.

7.2.1.1 *Capacity*

Static values; 972 TAF for CVP, 1067 TAF for SWP. Sum represents total capacity of San Luis Reservoir (2.04 MAF).

7.2.1.2 *Carryover_est*

SWP Only: Estimate of SWP carryover deliveries based on relationship with Oroville storage in CalSim II. WEAP does not simulate carryover deliveries, but this value is used so that SWP San Luis rule curve mimics CalSim II in October-December.

7.2.1.3 *DrainTarget*

For CVP this is 90 TAF plus 10% of CVP South-of Delta Annual Delivery Target minus 2000 TAF. For SWP this is 110 TAF.

7.2.1.4 *Delivery Target*

Annual delivery target for South-of-Delta deliveries.

7.2.1.5 *FillTarget*

Defines the target fill volume based on the *Delivery Target*.

7.2.1.6 *InactiveStorage*

Static values; 45 TAF for CVP, 55 TAF for SWP. Sum represents inactive storage at San Luis Reservoir (100 TAF).

7.2.1.7 *Observed*

This parameter reads historical values of CVP and SWP San Luis storage.

7.2.1.8 *OroDrainAmt4SL*

SWP only: Volume that can be moved from Oroville to SWP San Luis through the end of September, based on *OroSepTarg* and space available in SWP San Luis.

7.2.1.9 *OroDrainAmtMon*

SWP only: Volume that could be moved from Oroville to SWP San Luis in current month.

7.2.1.10 *OroSepTarg*

SWP only: End of September storage target for Oroville.

7.2.1.11 *Orovillestorage*

SWP only: Previous month storage in Oroville.

7.2.1.12 *Rule_Cap_Oroville*

SWP only: Maximum rule curve value based on Oroville storage.

7.2.1.13 *Rule_Cap_Shasta*

CVP only: Maximum rule curve value based on Shasta storage.

7.2.1.14 *RuleCurve*

Final calculation of rule curve, not less than *InactiveStorage* or more than *Capacity*.

7.2.1.15 *RuleCurveCalc*

Calculation of rule curve based on reservoir and fill and release requirements.

7.2.1.16 *Rule_max*

CVP only: maximum rule curve amount (1100 TAF).

7.2.1.17 *Rule_Sha_Cut*

CVP only: Cut in rule curve based on low Shasta storage conditions.

7.2.1.18 *SLCVP_storage*

CVP only: Previous month storage in CVP San Luis.

7.2.1.19 *SLSWP_storage*

SWP only: Previous month storage in SWP San Luis.

7.2.2 ExportOps

Exports from the Delta into the North Bay Aqueduct, Contra Costa Canal, DMC, and the California Aqueduct are limited by the physical capacities of the pumping stations and by regulatory standards within the Delta. These regulations include export limits based on inflows to the Delta and export limits based on San Joaquin River inflows during the spring pulse period (April 16 to May 15).

The following sections describe how these regulations are applied within SacWAM.

See also the section on Reverse Flows in the User-Defined Decision Variables and Constraints chapter (8.7).

7.2.2.1 *Vernalis Flow*

This parameter is simply the flow data of the San Joaquin River at Vernalis, pulled from *Supply and Resources\River\Inflow at Vernalis: Headflow*[CFS]. It plays a role in the USFWS Opinion Action 2 (7.2.1.14), the San Joaquin exports (7.2.2.6), both the Banks and Jones pumping plants' operations (7.2.2.2), the D-1641 rule (7.2.2.5), and the SWP operations (0).Pumping from the Delta at the Banks and Jones pumping plants is sometimes limited by San Joaquin River flows at Vernalis. These limits are discussed in greater detail in the following sections. SacWAM does not consider San Joaquin River water management operations upstream from Vernalis. Instead, the model reads in pre-processed timeseries of flows at Vernalis. The model offers two options for San Joaquin River flows: (1) CalSim II simulated flows at Vernalis or (2) timeseries of Vernalis flows developed by SWRCB as part of Phase 1 of the update to the Bay-Delta Plan. These flows are specified in SacWAM in the Data Tree under *Key Assumptions\Use Water Board Vernalis Inflow* (see Section 9.6).

7.2.2.2 *Banks and Jones*

The amount of water pumped at Banks and Jones is limited by physical and permit capacities at the two pumping plants. Under normal conditions, pumping is limited to their permit capacities. However, this is relaxed during certain months of the year if San Joaquin River flows at Vernalis exceed a threshold of 1000 cfs.

DaysIncrease

SWP Only: The number of days in the month where pumping is allowed to exceed the lower level permit capacity (i.e. Permit Cap1).

EWAReservedCap

SWP Only: The amount of capacity at the Banks pumping plant that is set aside to provide water for the environmental water account.

MaxAllow

The maximum amount of pumping that may occur at Banks and Jones Pumping Plants. This takes into account the physical capacities, permit capacities, and San Joaquin River flows at Vernalis.

MaxDiversion

The *MaxDiversion* is the minimum of the permitted capacity or D-1641 export limits imposed during the April-May pulse period.

MinPump

The minimum amount of export that needs to occur in order to meet health and safety (H&S) standards.

Permit Capacity

The maximum amount of water that is permitted to be pumped at the Jones Pumping Plant.

Permit Cap1

The maximum amount of water that is permitted to be pumped at the Banks Pumping Plant under dry-to-normal conditions (i.e. San Joaquin River flow at Vernalis is less than 1000 cfs).

Permit Cap2

The maximum amount of water that is permitted to be pumped at the Banks Pumping Plant under wet conditions (i.e. San Joaquin River flow at Vernalis greater than 1000 cfs during the period December 15th to March 15th).

Physical Capacity

The maximum amount of water that can physically be pumped at the Banks (4600 cfs) and Jones (10300 cfs) Pumping Plants.

7.2.2.3 *OMR*

The 2008 USFWS BiOp determined that the continued operation of the CVP and SWP would likely result in adverse modification to critical habitat of the delta smelt that would jeopardize the species' existence within the Delta. This jeopardy determination led to the development of a Reasonable and Prudent Alternative (RPA) that was designed to avoid the likelihood of these threats. RPA includes Components 1 and 2 that are intended to reduce Delta exports, as indexed by Old and Middle River (OMR) flows, when the entrainment risk of delta smelt increases. The implementation of these actions in SacWAM is described in the sections below.

OMR_background sets background flow standards at -5000 cfs from January to March and -8000 cfs from April to December in accordance with the RPA (Table 7-1).

Table 7-1. Old and Middle River Background Flow Standards

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
OMR Background		-8000 cfs			-5000 cfs				-8000 cfs			

2008 USFWS Biological Opinion Action 1

Action1 is intended for adult delta smelt entrainment protection during the winter pulse (December through March) and limits Delta exports so that OMR flows (*A1_OMR_Target*) are no more negative than -2,000 cfs for a total duration of 14 days when the three-day average turbidity at Prisoner's Point, Holland Cut, and Victoria Canal exceeds 12 nephelometric turbidity units (NTU). SacWAM uses the unimpaired Sacramento Valley Four Rivers Index (*SAC_RI*) (i.e. Sacramento River at Bend Bridge, Feather River at Oroville, Yuba River near Smartville, and American River at Folsom) as a surrogate for the turbidity trigger for this action—assuming that 20,000 cfs (*Turbidity_Threshold*) is a conservative indicator of the 12 NTU threshold.[11]

[11] It is important to note that using flows in this way implies that the unimpaired Sacramento Valley Four Rivers Index needs to be preprocessed for each climate scenario that SacWAM will run.

2008 USFWS Biological Opinion Action 2

Action2 is implemented as an adaptive process following Action 1 and is intended to protect pre-spawning adult delta smelt from entrainment after the winter pulse (January through April). Action 2 limits Delta exports so that OMR flows are no less negative than -5,000 to -3,500 cfs depending on existing conditions within the Delta. SacWAM uses the X2 position (see Section 7.2.6.1 in the Delta section of this chapter) as an indicator of existing Delta conditions. *X2_A2* looks to see whether X2 at the previous time step was east of Roe (>64 miles) or west of Roe (<64 miles); the model then uses the corresponding OMR standards (*OMR_Target_X2_E_Roe* or *OMR_Target_X2_W_Roe*) to determine the target flow for each month (*A2_OMR_Target*). The considerations for setting the Action 2 OMR standards are summarized in Table 7-2.

Table 7-2. Action 2 Old and Middle River Standard

	Minimum Flow (cfs)	
Sacramento Valley Water-Year Type	**X2 East of Roe (X2 > 64 miles)**	**X2 West of Roe (X2 < 64 miles)**
Critical	-3500	-5000
Dry	-3500	-5000
Below Normal	-3500	-5000
Above Normal	-3500	-5000
Wet	-3500	-5000

OMR flow requirements under Action 2 are suspended when the 3-day flow average is greater than 90,000 cfs in the Sacramento River at Rio Vista (*RioVista_Threshold*) and 10,000 cfs in the San Joaquin River at Vernalis (*Vernalis_Threshold*). When the flow at Vernalis (*Vernalis*) exceeds the Vernalis threshold, the trigger (*Vernalis_Trigger*) is activated. SacWAM uses a methodology developed by Hutton (2008) that uses monthly values to estimate the probability of the 3-day average flows exceeding these thresholds. The model suspends Action 2 when the probability exceeds 50 percent.

OMR flow requirements under Action 2 are suspended when the 3-day flow average is greater than 90,000 cfs in the Sacramento River at Rio Vista and 10,000 cfs in the San Joaquin River at Vernalis. The Rio Vista threshold is triggered using a timeseries of trigger months based on flow at Freeport, developed for CalSim II. This trigger is contained in the branch *Ops\OMR and Health and Safety\Int_Freeport*. When the flow at Vernalis (*Vernalis*) exceeds the Vernalis threshold, the trigger (*Vernalis_Trigger*) is activated. SacWAM uses a methodology developed by Hutton (2008) that uses monthly flow values (*Vernalis_Threshold*) to estimate the probability of the 3-day average flows exceeding the 10,000 cfs threshold at Vernalis. The model suspends Action 2 when this probability exceeds 50 percent.

2008 USFWS Biological Opinion Action 3

Action 3 is implemented as an adaptive approach intended to protect larval and juvenile delta smelt from entrainment. Similar to Action 2, Action 3 limits Delta exports so that OMR flows are no more negative than -5,000 to -1,250 cfs based on existing conditions within the Delta (existing conditions are determined in *X2_A3* ("between" in October of the current accounts year; determined by X2 position in previous time step for all other months); named in *A3_OMR_Target*; and assigned values in *OMR_Target_X2_E_Roe*, *OMR_Target_X2_Between*, and *OMR_Target_X2_W_Roe*). The considerations for setting the Action 3 OMR standards are summarized in (Table 7-3).

Table 7-3. Action 3 Old and Middle River Standard

Sacramento Valley Water-Year Type	Minimum Flow (cfs) X2 East of Roe (X2 > 74 mi)	X2 in between (64 mi < X2 < 74 mi)	X2 West of Roe (X2 < 64 mi)
Critical	-1250	-3500	-5000
Dry	-1250	-3500	-5000
Below Normal	-1250	-3500	-5000
Above Normal	-1250	-3500	-5000
Wet	-1250	-3500	-5000

Action 3 can be triggered either when the average temperatures from 3 stations within the Delta (Mossdale, Antioch, and Rio Vista) exceed 12 °C or when spent female delta smelt appear in the Spring Kodiak Trawl Survey or at Banks or Jones (*A3_Trigger_month* and *A3_Trigger_day*). These triggers are indicative of spawning activity and the probable presence of larval delta smelt in the South and Central Delta.

Both triggers are based on pre-processed data. The water temperature from the three monitoring stations has been found to be highly correlated to measured air temperature at the Sacramento Executive Airport. Therefore, SacWAM uses a timeseries of trigger dates based on air temperature developed for the CalSim II model (*Temp_Trigger_mo* and *Temp_Trigger_day*). Because SacWAM has no good way of tracking biological triggers within the model, it must also pre-process these data. For present purposes, the model is set up such that biological trigger is activated each year on May 15 (*Bio_Trigger_mo* and *Bio_Trigger_da*).

Action 3 is suspended after 30th June (*Temp_Offramp_mo* and *Temp_Offramp_day*) or once certain temperature thresholds have been reached, whichever comes first. The temperature 'off-ramp' used to suspend Action 3 is triggered whenever water temperature reaches a daily average of 25C for three consecutive days as Clifton Court Forebay. Unfortunately, there is no reliable correlation between water temperature at Clifton Court and nearby air temperature stations. Thus, for now, SacWAM uses only the temporal off-ramp criterion (June 30) to end Action 3.

The considerations for setting the USFWS BiOp OMR actions are summarized in Table 7-4.

Table 7-4. Schedule of USFWS Biological Opinion Old and Middle River Actions

Action 1 Triggered	Action 3 Triggered	December	January	February	March	April	May	June
December	February	OMR Bkgd Action 1	Action 2	Action 3			Action 3 until Off-Ramp, then OMR Bkgd	
	March	OMR Bkgd Action 1	Action 2		Action 3		Action 3 until Off-Ramp, then OMR Bkgd	
	April	OMR Bkgd Action 1	Action 2			Action 3	Action 3 until Off-Ramp, then OMR Bkgd	
	After Apr.	OMR Bkgd Action 1	Action 2			Action 3	Action 3 until Off-Ramp, then OMR Bkgd	
January	February	OMR Background	Action 1 Action 2	Action 3			Action 3 until Off-Ramp, then OMR Bkgd	
	March	OMR Background	Action 1 Action 2		Action 3		Action 3 until Off-Ramp, then OMR Bkgd	
	April	OMR Background	Action 1 Action 2			Action 3	Action 3 until Off-Ramp, then OMR Bkgd	
	After Apr.	OMR Background	Action 1 Action 2			Action 3	Action 3 until Off-Ramp, then OMR Bkgd	
February	February	OMR Background		Action 1 Action 3			Action 3 until Off-Ramp, then OMR Bkgd	
	March	OMR Background		Action 1 Action 2	Action 3		Action 3 until Off-Ramp, then OMR Bkgd	
	April	OMR Background		Action 1 Action 2		Action 3	Action 3 until Off-Ramp, then OMR Bkgd	
	After Apr.	OMR Background		Action 1 Action 2		Action 3	Action 3 until Off-Ramp, then OMR Bkgd	
March	February	OMR Background		Action 3			Action 3 until Off-Ramp, then OMR Bkgd	
	March	OMR Background		Action 1	Action 3		Action 3 until Off-Ramp, then OMR Bkgd	
	April	OMR Background		Action 1	Action 2	Action 3	Action 3 until Off-Ramp, then OMR Bkgd	
	After Apr.	OMR Background		Action 1	Action 2	Action 3	Action 3 until Off-Ramp, then OMR Bkgd	

Note that Action 3 may be triggered at any day of the month based on the pre-processed timeseries. (This is not shown in Table 7-4.)
Key: Bkgd=Background; OMR=Old and Middle River.

RPA

The RPA branches set the flow standards associated with each action depending upon the timing in which each action was triggered.

7.2.2.4 *ExportInflow*

In each month, total Delta exports are limited by a certain fraction of the inflow to the Delta. This is referred to as the Export/Inflow (or E/I) ratio (*ExpRatio*). The E/I ratio limits Delta exports to 65 percent of inflow February through June and to 35 percent July through January (*EI_base*). However, in February, the E/I ration may be increased to 70 percent if the Eight Rivers Index is less than 1.5 MAF or increased to 75 percent if the Eight Rivers Index is less than 1 MAF (*Feb_adjust*). Delta inflows are estimated as the sum of Sacramento River flows at Freeport, San Joaquin River flows at Vernalis, and Delta inflows from the Yolo Bypass, Mokelumne River, and Calaveras River.

Delta exports are also adjusted during the spring pulse period (April 16 – May 15) according the 2009 NMFS BiOp (NMFS, 2009), which limits export levels based on the 60-20-20 San Joaquin Valley Water Year Classification. According to this schedule, the projects are always allowed to export a minimum of 1500 cfs. If San Joaquin River flows at Vernalis exceed 1500 cfs, then exports during the pulse period are limited to a defined ratio of Vernalis flow to exports depending on the water-year type (WYT) (Table 7-5).

Table 7-5. Delta Export Limits during Spring Pulse Period

San Joaquin Valley Water-Year Type	Pulse Period Vernalis Flow: Export Ratio
Critical	1 to 1
Dry	2 to 1
Below Normal	3 to 1
Above Normal	4 to 1
Wet	4 to 1

The physical capacity to pump water into the California Aqueduct at the Banks pumping plant is 8,500 cfs. However, the permitted capacity at Banks, established under Section 10 of the Rivers and Harbors Act (1968), is only 6,680 cfs. SacWAM includes adjustments to the permitted capacity according to a proposal from DWR to increase the SWP diversions by one-third of the San Joaquin River flow at Vernalis during the period from mid-December through mid-March when Vernalis flows exceed 1,000 cfs.

7.2.2.5 *D1641_PulsePeriod*

D1641 is a SWRCB Decision outlining flow and water quality requirements in the Delta watershed. It includes a 31-day pulse flow period from April 15 to May 15 that is intended to facilitate fish migration. During this period, exports are limited to the greater of 1500 cfs or the San Joaquin River flow at Vernalis. The pumping limits defined here are applied using UDCs (see *AprMayPulse_CVP* and *AprMayPulse_SWP* under *UDC\Pumping Constraints*).

7.2.2.6 *SJR_EIRatio*

San Joaquin exports depend on the month and on hydrologic indices (see Section 7.2.7.13). Maximum exports (*SJ_MaxExp*) are set at 99,999 in June through March and in April and May when *Vernalis Flow* is greater than 21,750 cfs. Further rules for April and May are explained in Table 7-6.

Table 7-6. San Joaquin Maximum Exports

Time Step	San Joaquin Hydrologic Index	SJ_MaxExp (cfs)	
June – March	N/A	99,999	
April, May	≤2	The greater of Health and Safety levels and…	Vernalis Flow/4
	3		Vernalis Flow/3
	4		Vernalis Flow/2
	Other		Vernalis Flow

*Health and Safety level explained in Section 7.2.2.7

7.2.2.7 *RPAHealthandSafety*

The H&S flow level (1500 cfs) is used in calculating the San Joaquin River export-import ratio (see Section 7.2.2.6).

7.2.2.8 *OMR and Health and Safety*

This section computes the OMR RPA reverse flow limits and maximum exports. It contains the following variables:

- **Q_SOD_HS,** calculates diversions from the Delta when total CVP and SWP exports are at H&S levels as specified under the USFWS BiOp (1500 cfs). This sums H&S pumping with *CCWD_EstimateDiversions* and *SODNetCU*.
- **CCWD_EstimatedDiversions,** estimated Delta diversions by Contra Costa WD.
- **Q_OMR_HS,** OMR flows if Delta diversions are at minimum H&S levels.
- **Q_OMR_Bound,** OMR maximum reverse flows under the OMR RPA.
- **Q_OMR_ReverseBound,** converts *Q_OMR_Bound* to a positive value (because reverse flows in SacWAM are calculated as a positive flow). This is the limit that is applied to flows in the OMR (see *UDCs\OMR_BO_Actions\OMR Constraints\Set Q_OMR_Final*).
- **Available Export,** computes the available export capacity for CVP and SWP combined under the OMR reverse flows standard. This is used to split available export capacity between CVP and SWP (see *UDCs\OMR_BO_Actions\OMR Constraints\ShareAvailableExport*).
- **Int_Freeport,** timeseries input data that defines when Rio Vista flows are above the threshold for suspending OMR RPA Action 2.
- **SODNetCU,** in-Delta consumptive use.

7.2.3 Flow Requirements

SacWAM considers specific river flow requirements for water quality, fish and wildlife, navigation, recreation, downstream, and others through specification of a flow requirement object associated with points on a river. Flow requirements are treated as a demand and are satisfied in accordance with the user-defined priority structure. Many of the flow requirements vary seasonally and are adjusted depending on WYT. Flow requirements associated with regulatory requirements are listed in Table 7-7. They are described in more detail in the sections that follow.

Table 7-7. Flow Requirements in SacWAM

River	Location	Alias in WEAP tree	Description	Water-Year Adjustment
Trinity	Below Lewiston Dam	BlwCLE	Trinity Record of Decision (2000)	Trinity River Index
Clear	Below Whiskeytown Dam	MinFlow	MOA with CDFW (1960)	Shasta Index
	Below Whiskeytown Dam	Temperature; CVPIA B2	CVPIA B2 (1992) and AFRP	None
		NMFS	NMFS BiOp (2009)	None
Sacramento	Below Keswick Dam	WR90_5	SWRCB WR 90-5 (1990)	Sacramento Valley Index
	Below Keswick Dam	NMFS BiOp	NMFS BiOp (2009)	None
	Wilkins Slough	NCP	NMFS BiOp (2009)	Shasta Storage
	Rio Vista	at Rio Vista	Water Right Decision 1641 (1999)	Sacramento Valley Index
Feather	Low Flow Channel	LowFlowChannel	SWRCB order WQ 2010-016	None
	High Flow Channel	HighFlowChannel	DWR/CDFW MOU (1983)	Forecasted Feather River April-July Runoff
	Mouth of Feather River	Verona	DWR/CDFW MOU (1983)	Forecasted Feather River April-July Runoff
Yuba	Smartville	nr Smartville	Lower Yuba River Accord (2008)	North Yuba Index
	Marysville	nr Marysville	Lower Yuba River Accord (2008)	North Yuba Index
Bear	Below CFWID diversion	BlwCampFarWest	Settlement Agreement (1994)	Sacramento Valley Index
American	Below Folsom Dam	FMS	Lower American River Flow Management Standard (2006)	Four Reservoirs Index, Impaired Folsom Inflow Index, Folsom Storage, and Sacramento Valley Index
Mokelumne	Below Camanche	blw Camanche	FERC Project No. 2916-004 Joint Settlement Agreement (1996)	Mokelumne Index
	Below Woodbridge	Woodbridge	FERC Project No. 2916-004 Joint Settlement Agreement (1996)	Mokelumne Index
Sacramento-San Joaquin Delta	*Delta Outflow*	D1641 Base, MRDO	Water Right Decision 1641 (1999)	Sacramento Valley Index and Eight Rivers Index
Putah		DroughtIndicator		

Key: AFRP=Anadromous Fish Restoration Program; BiOp=Biological Opinion; CDFW=California Department of Fish and Wildlife; CVPIA=Central Valley Project Improvement Act; DWR=California Department of Water Resources; FERC=Federal Energy Regulatory Commission; MOA= Memorandum of Agreement; MOU=Memorandum of Understanding; MRDO=minimum required Delta outflow; NMFS=National Marine Fisheries Service.
Note: Names of Flow Requirements as they appear in WEAP are italicized in this table.

Each of these MFRs is associated with a Flow Requirement object in SacWAM. They all reference flow schedules that are defined in the Data Tree under *Other Assumptions\Ops\Flow Requirements* and are described in more detail below.

7.2.3.1 *Trinity River*

Trinity River flow requirements are based on the December 19, 2000 Trinity River Mainstem Record of Decision, which allocates 368.6 TAF to 815 TAF annually for Trinity River flows. These are contained in *BlwCLE* and summarized in Table 7-8.

Table 7-8. Lewiston Dam Releases to the Trinity River

Trinity River Water-Year Type	Minimum Flow (cfs)											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Critically Dry	373	300					600	1,498	783	450		
Dry	373	300					540	2,924	783	450		
Normal	373	300					477	4,189	2,120	1,102	450	
Wet	373	300					460	4,709	2,526	1,102	450	
Extremely Wet	373	300					427	4,570	4,626	1,102	450	

7.2.3.2 *Clear Creek*

SacWAM defines a flow requirement on Clear Creek below Whiskeytown Reservoir according to the 1960 Memorandum of Agreement (MOA) with CDFW, flow and temperature requirements under the USFWS Anadromous Fish Restoration Program (AFRP), and the 2009 NMFS BiOp. The flow requirement (*BlwWKTN*) is the maximum of the MFRs set by the various regulations. The minimum flow schedules are summarized in Table 7-9. 1960 MOA flows are in branch *BlwWKTWN\MinFlow*. AFRP flows (*BlwWKTWN\CVPIA B2*) are released under authority CVPIA Section 3406(b)(2). The AFRP also has temperature requirements of 60 degrees F during July-Sep, so flow releases that will maintain those temperatures are also implemented (*BlwWKTWN\Temperature).* The values of these requirements were obtained from Derek Hilts and Matt Brown at USFWS, respectively. In addition to these flows, the 2009 NMFS BiOp requires a flow of 600 cfs for six days in May. Thus, the flow requirement below Whiskeytown in May is a daily weighted average of these pulse flows (*BlwWKTWN\NMFS)* and the maximum of other applicable requirements.

Table 7-9. Clear Creek Minimum Flow Requirements below Whiskeytown

Regulation	Flow Requirement (cfs)											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1960 MOA Shasta Critical years	30	70		30								
1960 MOA Otherwise	50	100		50								
AFRP (CVPIA b(2) flows)	200								150	85		150
AFRP flows for temperature	0								70	100		70

Key: AFRP=Anadromous Fish Restoration Program; CVPIA= Central Valley Project Improvement Act; MOA=Memorandum of Agreement.

7.2.3.3 *Sacramento River*

SacWAM defines a flow requirement on the Sacramento River below Keswick Dam (*BlwKeswick*). The final requirement is the minimum of a series of flow requirements described here. Table 7-10 shows minimum flows under SWRCB WR90-5 (*WR90_5*). A flow requirement of 3250 cfs all year round is also implemented in the model (*NMFS BiOp*), based on minimum flows in the 2009 NMFS BiOp and standard operations to meet downstream temperature requirements under WR90-5 and the 2009 NMFS BiOp. 3,250 cfs is a standard value used in the CalSim II model to represent minimum flows at Keswick for meeting temperature standards. Lastly, under CVPIA (b)(2) there are flow releases that are implemented in November and December under higher storage conditions. These requirements are 4,000 cfs in November, and the lower of 4,000 cfs or 75% of November flow in December. Values for these requirements are from Derek Hilts (USFWS). These requirements are implemented in WEAP (*CVPIA_B2*) when Shasta storage in the prior September is > 2,400 TAF.

Table 7-10. Sacramento River Minimum Flow below Keswick: SWRCB WR90-5

Sacramento Basin	Minimum Flow (cfs)											
Water-Year Type	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Critically Dry	2,800		2,000			2,300						2,800
Otherwise	3,250					2,300						3,250

Historically there has been a flow requirement of 5,000 cfs at Wilkins Slough to maintain flows for navigation (*NCP*). In order to conserve Shasta cold water pool storage for summer releases, the 2009 NMFS BiOp allows for relaxation of this requirement in lower storage conditions. Relaxation is done on a discretionary basis (i.e. no fixed rules have been defined), so in the model the requirement is relaxed when Shasta storage is lower than the thresholds shown in Table 7-11 (*NCP_base*). This operation approximately mimics the current operation in the CalSim II model. Because of the distance between Shasta Dam and Wilkins Slough and the unpredictability of downstream unregulated flows, CalSim II includes an increase in reservoir releases in some months to take into account this uncertainty. This additional release requirement is included in SacWAM as a calibration factor (*Daily adjustment*) that can be turned on to facilitate comparisons to the CalSim II model. The default setting is to have this adjustment off.

Table 7-11. Sacramento River Minimum Flow for Navigation at Wilkins Slough

Shasta Storage (TAF) in April	Requirement (cfs)
<= 2,500	3,250
<= 3,500	3,500
<= 3,900	4,000
<= 4,100	4,500
Otherwise	5,000

SWRCB Decision 1641 includes flow requirements on the Sacramento River at Rio Vista as part of the suite of actions intended to protect water quality within the Delta. SacWAM implements these flow requirements according to Table 7-12 (*at Rio Vista*).

Table 7-12. Sacramento River Minimum Flow at Rio Vista - D-1641

Sacramento	Minimum Flow (cfs)											
Basin Water-Year Type	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Critically Dry	3,000	3,500	3,500	0								3,000
Otherwise	4,000	4,500	4,500	0								3,000

7.2.3.4 *Feather River*

Flow requirements on the Feather River are governed by a 1983 Memorandum of Understanding (MOU) between DWR and CDFW (formerly California Department of Fish and Game) and a 2010 SWRCB order (WQ 2010-016). The 1983 MOU establishes MFRs on the Feather River within the low-flow channel (i.e. main channel of Feather River below Oroville and above Thermalito Afterbay outlet) and the high-flow channel (i.e. Feather River below Thermalito Afterbay outlet and Verona at the confluence with the Sacramento River). Under WQ 2010-016 the low-flow channel requirements (*LowFlowChannel*) were increased from 600 cfs year-round to 800 cfs from September 9 to March 31, and 700 cfs the remainder of the time. The flow requirement in the high-flow channel (*DFG_DWR 1983 MOA*) varies from 1000 to 1700 cfs, depending on the month and also on whether the April-to-July unimpaired inflow to Oroville (*DFG_DWR 1983 MOA/PrevAprJulRunoff*) is less than 55 percent of normal (*DFG_DWR 1983 MOA/PercentOfNormal*). Under certain low storage conditions in Oroville these requirements are lowered to an off-ramp level of flows. The storage criteria for this off-ramp is not explicitly modeled in SacWAM, but a timeseries of off-ramp periods is taken from CalSim II (*DFG_DWR 1983 MOA/Offramp*). These high-flow channel requirements are summarized in Table 7-13. A final aspect of the high-flow channel requirement is that if the highest peak streamflow between October 15 and November 30 is > 2500 cfs because of project operations and not flood flow, then the requirement for November to March is increased to 500 cfs below that peak flow (*Fall based HFC minflow*). In order to avoid this requirement, high-flow channel flows are constrained to be < 4000 cfs in October and 2500 cfs in November, except when Oroville is spilling (see *Fall based HFC minflow /HighFlow Channel max* and *User Defined LP Constraints\Oroville Fall Operations*). Lastly, flows at the mouth of the Feather (*Verona*) are also maintained at the flow levels in Table 7-13.

Table 7-13. Feather River Minimum Flow from Thermalito Afterbay Outlet to Mouth

<table>
<tr><th rowspan="2">Forecasted April through July Unimpaired Runoff (percent of normal)</th><th colspan="12">Minimum Flow (cfs)</th></tr>
<tr><th>Oct</th><th>Nov</th><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th></tr>
<tr><td>55 percent or greater</td><td colspan="6">1,700</td><td colspan="6">1,000</td></tr>
<tr><td>Less than 55 percent</td><td colspan="5">1,200</td><td colspan="7">1,000</td></tr>
<tr><td>Off-ramp flows</td><td colspan="5">900</td><td colspan="7">750</td></tr>
</table>

7.2.3.5 *Yuba River*

SacWAM sets flow requirements for the Yuba River near Smartville (*nr Smartville*) and at Marysville (*nr Marysville*) according to the Lower Yuba River Accord (2008). Flow schedules determinations begin in February and are updated through May based on refinements of the North Yuba Index. Thresholds for the flow schedules are summarized Table 7-14 and Table 7-15. The North Yuba Index values are defined under Hydrologic Indices (see Section 7.2.7.4).

Table 7-14. Yuba River Minimum Flow near Smartville

<table>
<tr><th rowspan="2">North Yuba Index (TAF)</th><th colspan="12">Minimum Flow (cfs)</th></tr>
<tr><th>Oct</th><th>Nov</th><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th></tr>
<tr><td><= 820</td><td colspan="6">700</td><td>350</td><td colspan="4">0</td><td>700</td></tr>
<tr><td>Otherwise</td><td colspan="2">600</td><td colspan="4">550</td><td>300</td><td colspan="4">0</td><td>500</td></tr>
</table>

Table 7-15. Yuba River Minimum Flow at Marysville

<table>
<tr><th rowspan="2">North Yuba Index (TAF)</th><th colspan="12">Minimum Flow (cfs)</th></tr>
<tr><th>Oct</th><th>Nov</th><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th></tr>
<tr><td><= 693</td><td colspan="6">350</td><td>425</td><td>450</td><td>225</td><td colspan="2">150</td><td>350</td></tr>
<tr><td><= 820</td><td>400</td><td colspan="5">500</td><td>550</td><td>500</td><td colspan="4">400</td></tr>
<tr><td><= 920</td><td>400</td><td colspan="5">500</td><td colspan="2">750</td><td colspan="4">400</td></tr>
<tr><td><= 1040</td><td colspan="6">500</td><td>700</td><td>900</td><td colspan="4">500</td></tr>
<tr><td><= 1400</td><td colspan="5">500</td><td>700</td><td>750</td><td>1,000</td><td>650</td><td colspan="3">500</td></tr>
<tr><td>Otherwise</td><td colspan="5">500</td><td>700</td><td>1,000</td><td>2,000</td><td>1,500</td><td>700</td><td>600</td><td>500</td></tr>
</table>

7.2.3.6 *Bear River*

According to a 1994 settlement agreement between South Sutter WD, Camp Far West Irrigation District (CFWID), and DWR, water rights require a minimum streamflow below the diversion CFWID diversion works of 25 cfs from April 1 through June 30 and 10 cfs from July 1 through March 30 (*BlwCampFarWest\MinFlow*). The agreement also calls for flows to increase to 37 cfs for up to sixty days July through September in dry and critical years. For purposes of modeling, SacWAM assumes that these sixty days occur in July and August (*BlwCampFarWest\DryCritical_adjust*). See Table 7-16.

Table 7-16. Bear River Minimum Flows below Camp Far West Irrigation District Diversion

<table>
<tr><th rowspan="2">Sacramento Basin Water-Year Type</th><th colspan="12">Minimum Flow (cfs)</th></tr>
<tr><th>Oct</th><th>Nov</th><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th></tr>
<tr><td>Dry and Critically Dry</td><td colspan="9">0</td><td colspan="2">37</td><td>0</td></tr>
<tr><td>Otherwise</td><td colspan="6">10</td><td colspan="3">25</td><td colspan="3">10</td></tr>
</table>

7.2.3.7 *American River*

The lower American River has two flow requirements. The first is D-893 (*D893*), which was established in 1958. Table 7-17 shows D-893 flow requirements. The critical year requirement applies only if March through September unimpaired inflow into Folsom is projected to be < 600 TAF *(D893WYT*).

Table 7-17. D-893 Requirements

	Flow Requirements (cfs)	
Month	**Normal Year**	**Critical Year**
Jan-Mar	250	250
Apr-Aug	250	188
Sep	375	281
Oct-Nov	500	375
Dec	500	500

The second flow requirement is governed by the Flow Management Standard (*FMS*), which was established in 2006 as a framework to improve the condition of aquatic resources in the lower American, particularly fall-run Chinook and steelhead. The FMS is intended to provide 800-2,000 cfs in the lower American River depending on the time of the year. These MFRs are set by the FMS with consideration to hydrologic indices, which take into account the vast majority of water availability conditions in the basin. The implementation of the FMS in SacWAM is based on the Lower American River FMS 2008 Technical Report, which included revisions to an earlier 2006 report.

The FMS uses three main indicators of water availability to make adjustments to MFRs depending on the time of the year. These three indices are the Four Reservoir Index (FRI), the Sacramento River Index (SRI), and the Impaired Folsom Inflow Index (IFII). The FRI is an index of the end-of-September combined carryover storage in Folsom, French Meadows, Hell Hole, and Union Valley reservoirs (*FRI*). FRI is used to adjust flow requirements early in the water year (i.e. October through December) when there is little or no data available to support runoff forecasts. Table 7-18 summarizes how SacWAM uses FRI to set MFRs October to December (*OctDecIndexFlow*).

Table 7-18. October-December Adjustments to Lower American River Flow Requirement

Four Reservoir Index	Minimum Flow Requirement (cfs)
0	800
600	800
746	1,750
796	1,750
848	2000
Maximum Storage	2000

In January and February, FMS uses SRI to make adjustments to flow requirements on the lower American. SRI is an index of the forecasted water year runoff for the entire Sacramento River Basin and is a better measure of near-term water availability. SacWAM adjusts flow requirements based on SRI using the criteria in Table 7-19.

Table 7-19. January-February Adjustments to Lower American Flow Requirement

SRI (MAF)	SRI Water-Year Type	Lower American River Flow Requirement
>= 15.7	Above Normal, or Wet	1750 cfs
>= 10.2 and < 15.7	Below Normal, or Dry	Minimum 1750 cfs or previous month MFR
< 10.2	Critically Dry	Maximum 800 cfs or 85 percent previous month MFR

MAF=million acre-feet; MFR= minimum flow requirement; SRI=Sacramento River Index

The January and February MFR is subject to further adjustments based on beginning-of-month storage in Folsom Reservoir. If Folsom Reservoir storage is less than 300 TAF in January or 350 TAF in February and storage is not at the flood curve, then the MFR is set to 85 percent of the previous month MFR or 800 cfs, whichever is greater (Table 7-19; *FMS\JanFeb*).

The IFII is an index of the volume of flow into Folsom Reservoir from May through September after all legal diversions take place in the upstream watershed. The IFII is used to set flow requirements from March through the remainder of the water year, when water supply availability is reasonably certain and can be used to make informed flow management decisions (Table 7-20 and Table 7-21). SacWAM sets MFRs March-May (*MarMay*) based on the IFII and the predicted end-of-May storage in Folsom Reservoir (*EoMayStorageEst*). It uses a similar approach for setting June-August MFRs (*JunAug*) based on the IFII (*InflowForecast*) and the end-of-September storage in Folsom Reservoir (*EoSepStorageEst*). Using only the IFII predictions of total inflow, SacWAM uses the following tables to set March-September MFRs. The MFR in September is the weighted average of the MFRs for the two parts of the month before and after Labor Day.

Table 7-20. March-Labor Day Adjustments to Lower American River Flow Requirement

IFII (TAF)	MFR (cfs)
0	800
375	800
550	1750
9000	1750

Key: IFII=Impaired Folsom Inflow Index; MFR=minimum flow requirement.

Table 7-21. Post–Labor Day-September Adjustments to Lower American River Flow Requirement

Impaired Folsom Inflow Index (TAF)	Minimum Flow Requirement (cfs)
0	800
375	800
504	1,500
9,000	1,500

Key: cfs=cubic feet per second; TAF=thousand acre-feet

However, if SacWAM estimates that the end-of-May Folsom storage will be less than 700 TAF when releasing the MFR, then the March-May MFR is set to the lesser of the IFII-based MFR and the February MFR. Similarly, if SacWAM estimates that the end-of-September Folsom storage will be less than 300 TAF when releasing the MFR, then the June-September MFR is set to the maximum of 250 cfs or the computed release throughout those months which will lead to an end-of-September storage of 300 TAF.

The FMS also has criteria for conference years and off-ramp conditions, which can apply in any month and if satisfied will reduce the flow requirement to the same as the D-893 Normal Year requirement. Conference years occur when the predicted March-November unimpaired inflow to Folsom Reservoir is < 400 TAF. Off-ramp conditions are triggered during October through February when storage at the end of the current month is projected to fall below 200 TAF (*OctDecStorage*, *JanFebStorage)*. They are triggered March through September if the projected end-of-September storage is less than 200 TAF (*MarSepStorage*). Off-ramp conditions are halted whenever storage is projected to be above 200 TAF.

7.2.3.8 *Mokelumne River*

The Mokelumne River has two flow requirements that are defined by the Mokelumne River Joint Settlement Agreement (JSA) (FERC Project 2916; Joint Settlement Agreement, 1996). These flow requirements are set below Camanche Dam (*blw Camanche*) and at Woodbridge (*Woodbridge*).

blw Camanche

Flow requirements below Camanche Reservoir for the months November through March (*blw Camanche\NovMar*; Table 7-22) are based on storage in Pardee and Camanche Reservoirs at the beginning of November (*blw Camanche\OctStorage*; Table 7-23). Flow requirements for the months April through October (*blw\AprOct*; Table 7-22) are based on the Mokelumne River hydrologic WYT (discussed in Section 7.2.7.5 on Hydrologic Indices in the Mokelumne). Additional flow (*blw Camanche\AprOct\Additional*) is possible in May normal and wet years when storage in the reservoirs is not far below the storage capacity less the flood space requirement (*blw Camanche\BMAS*).

Table 7-22. Mokelumne River Minimum Flow below Camanche Dam

<table>
<tr><th rowspan="2">Mokelumne River Water-Year Type</th><th colspan="12">Minimum Flow (cfs)</th></tr>
<tr><th>Oct[1]</th><th>Nov[2]</th><th>Dec[2]</th><th>Jan[2]</th><th>Feb[2]</th><th>Mar[2]</th><th>Apr[1]</th><th>May[1]</th><th>Jun[1]</th><th>Jul[1]</th><th>Aug[1]</th><th>Sep[1]</th></tr>
<tr><td>Critically Dry</td><td>115</td><td colspan="6">130</td><td colspan="5">100</td></tr>
<tr><td>Dry</td><td colspan="8">220</td><td colspan="4">100</td></tr>
<tr><td>Below Normal</td><td colspan="9">250</td><td colspan="3">100</td></tr>
<tr><td>Normal and Above Normal</td><td colspan="9">325</td><td colspan="3">100</td></tr>
</table>

Notes:

1. Indicates minimum flow below Camanche is based on the Mokelumne River water-year type as determined by annual water yield.
2. Indicates minimum flow below Camanche is based on the Mokelumne River water-year type as determined by beginning-of-November storage in Pardee and Camanche reservoirs.

Table 7-23. Mokelumne River Water-Year Type Based on Beginning-of-November Reservoir Storage

Water-Year Type	Beginning of November Pardee/Camanche Storage
Critically Dry	269 TAF or less
Dry	270 TAF to 399 TAF
Below Normal	400 TAF to Max Allowable
Normal/Above Normal	Max Allowable

Woodbridge

The same as below Camanche, the flow requirements at Woodbridge (*Woodbridge*) for the months November through March (*Woodbridge\NovMar*; Table 7-24) are based on storage in Pardee and Camanche Reservoirs at the beginning of November (*blw Camanche\OctStorage*; Table 7-23); and for April through October (*Woodbridge\AprOct*) on Mokelumne River hydrologic WYT (discussed in Section 7.2.7.5 on Hydrologic Indices in the Mokelumne).

Table 7-24. Mokelumne River Minimum Flow at Woodbridge

<table>
<tr><th rowspan="2">Mokelumne River Water-Year Type</th><th colspan="12">Minimum Flow (cfs)</th></tr>
<tr><th>Oct†</th><th>Nov*</th><th>Dec*</th><th>Jan*</th><th>Feb*</th><th>Mar*</th><th>Apr†</th><th>May†</th><th>Jun†</th><th>Jul†</th><th>Aug†</th><th>Sep†</th></tr>
<tr><td>Critically Dry</td><td>45</td><td colspan="6">75</td><td colspan="5">15</td></tr>
<tr><td>Dry</td><td colspan="6">80</td><td colspan="2">150</td><td colspan="4">20</td></tr>
<tr><td>Below Normal</td><td colspan="6">100</td><td>150</td><td colspan="2">200</td><td colspan="3">20</td></tr>
<tr><td>Normal and Above Normal</td><td colspan="6">100</td><td>150</td><td colspan="2">300</td><td colspan="3">25</td></tr>
</table>

†Indicates minimum flow below Camanche is based on the Mokelumne River water-year type as determined by annual water yield.
*Indicates minimum flow below Camanche is based on the Mokelumne River water-year type as determined by beginning-of-November storage in Pardee and Camanche reservoirs.

Electra

Flow requirements at Electra (*ElectraDiversionDam*) depend on the WYT of the North Fork of the Mokelumne (discussed in Section 7.2.7.5 on Hydrologic Indices in the Mokelumne).

Table 7-25. Mokelumne River Minimum Flows below Electra Diversion Dam

<table>
<tr><th rowspan="2">North Fork Mokelumne Water-Year Type</th><th colspan="12">Minimum Flow (cfs)</th></tr>
<tr><th>Oct</th><th>Nov</th><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th></tr>
<tr><td>Critically Dry</td><td>15</td><td colspan="3">20</td><td>25</td><td>30</td><td>40</td><td>60</td><td>40</td><td>20</td><td colspan="2">15</td></tr>
<tr><td>Dry</td><td colspan="3">20</td><td>25</td><td>30</td><td>50</td><td>80</td><td>95</td><td>50</td><td colspan="3">20</td></tr>
<tr><td>Below Normal</td><td>20</td><td>25</td><td>30</td><td colspan="2">40</td><td>80</td><td>135</td><td>250</td><td>180</td><td>35</td><td colspan="2">20</td></tr>
<tr><td>Normal and Above Normal</td><td colspan="2">20</td><td>40</td><td colspan="2">60</td><td>110</td><td>190</td><td>490</td><td>270</td><td>40</td><td colspan="2">20</td></tr>
<tr><td>Wet</td><td>20</td><td colspan="2">50</td><td>90</td><td>120</td><td>150</td><td>400</td><td>980</td><td>850</td><td>145</td><td>30</td><td>20</td></tr>
</table>

SaltandLowerBearDams

P137 places additional flow requirements below the Salt Spring and Lower Bear dams (*SaltandLowerBearDams*) based on the North Fork Mokelumne WYT (discussed in Section 7.2.7.5 on Hydrologic Indices in the Mokelumne) (Table 7-26).

Table 7-26. Mokelumne River Minimum Flows below the Salt and Lower Bear Dams

<table>
<tr><th rowspan="2">North Fork Mokelumne Water-Year Type</th><th colspan="12">Minimum Flow (cfs)</th></tr>
<tr><th>Oct</th><th>Nov</th><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th></tr>
<tr><td>Critically Dry</td><td>19</td><td colspan="3">24</td><td>31</td><td>36</td><td>50</td><td>68</td><td>46</td><td>24</td><td colspan="2">19</td></tr>
<tr><td>Dry</td><td>24</td><td colspan="2">26</td><td>31</td><td>38</td><td>50</td><td>85</td><td>90</td><td>48</td><td>26</td><td colspan="2">24</td></tr>
<tr><td>Below Normal</td><td>24</td><td>26</td><td>33</td><td colspan="2">50</td><td>85</td><td>135</td><td>250</td><td>180</td><td>40</td><td>26</td><td>24</td></tr>
<tr><td>Normal and Above Normal</td><td>26</td><td>28</td><td>40</td><td colspan="2">64</td><td>110</td><td>200</td><td>500</td><td>270</td><td>45</td><td colspan="2">26</td></tr>
<tr><td>Wet</td><td>26</td><td colspan="2">58</td><td>95</td><td>130</td><td>160</td><td>425</td><td>1040</td><td>790</td><td>175</td><td>35</td><td>26</td></tr>
</table>

Lodi Rqmnts

The baseflow requirement below Electra Power House (*ElectraPowerhouse*) is 300 cfs in May, June, and July and 200 in other months (*Lodi Rqmnts\Base*). Flow requirements are never below base values. The actual flow requirement is the maximum of the base and other monthly values, which are determined by whether PG&E storage in the previous May in the reservoirs of the Upper Mokelumne (*PGandEMayStorage*) was above 130 TAF (*Lodi Rqmnts\HiMayStorage*) or below 130 TAF (*Lodi Rqmnts\LoMayStorage*). The resulting flow requirements are presented in Table 7-27.

Table 7-27. Lodi Flow Requirements

<table>
<tr><th rowspan="2">Upper Mokelumne Reservoir Storage</th><th colspan="12">Minimum Flow (cfs)</th></tr>
<tr><th>Oct</th><th>Nov</th><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th></tr>
<tr><td>Hi May storage (>130 TAF)</td><td colspan="3">500</td><td>400</td><td colspan="3">200</td><td>300</td><td colspan="4">500</td></tr>
<tr><td>Low May storage (<130 TAF)</td><td colspan="7">200</td><td colspan="5">300</td></tr>
</table>

7.2.3.9 *Delta Outflow*

SacWAM includes Delta standards that are specified in the 1995 Bay-Delta Plan (SWRCB, 1995) and D-1641[12] (SWRCB, 2000). Modeled standards for the Delta include the following:

- Net Delta Outflow Index (NDOI), expressed as a flow
- Salinity standards at Emmaton and Jersey Point expressed in electrical conductivity (EC)
- X2 location, expressed in kilometers

The NDOI and the outflow requirements to meet the salinity and X2 standards, combine to determine the minimum required net Delta outflow (*OutflowRequirement*). The Net Delta Outflows to meet water quality objectives for fish and wildlife beneficial uses as defined under D-1641 are summarized in Table 7-12. These flow requirements are adjusted in January according to the Eight Rivers Index and in May and June according to the Sacramento Valley Index. Flow requirements are increased to 6000 cfs in January if the Eight Rivers Index exceeds 800 TAF (*Jan_adjustment*). Flow requirements are decreased to 4000 cfs in May and June if the Sacramento Valley Water Year Index is less than 8.1 MAF (*MayJun_adjustment*).

[12] Decision 1641 (or D-1641) is the implementation plan for the 1995 Bay-Delta Plan, with respect to the operation of California's State Water Project and the USBR's Central Valley Project. D-1641 was adopted by SWRCB in December 1999 and subsequently revised in March 2000. It includes water quality objectives to protect beneficial uses for agriculture, municipal and industrial, and fish and wildlife in the Delta. It also defines water quality and flow objectives for various compliance monitoring stations throughout the Delta.

Table 7-28. Sacramento River Minimum Net Delta Outflow - D-1641

Mokelumne River Water-Year Type	Minimum Flow (cfs)											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Critically Dry	3,000	3,500		4,500	7,100					4,000	3,000	3,000
Dry	4,000	4,500			7,100					5,000	3,500	3,000
Below Normal	4,000	4,500			7,100					6,500	4,000	3,000
Above Normal	4,000	4,500			7,100					8,000	4,000	3,000
Wet	4,000	4,500			7,100					8,000	4,000	3,000

Outflow requirements to meet Delta salinity and standards are discussed in detail in Section 7.2.6.2.

7.2.3.10 *Putah Creek*

If March storage at Lake Berryessa is less than 750 TAF, the system is determined to be in drought (*DroughtIndicator*).

7.2.4 Priorities

WEAP uses LP to solve the allocation of water at each time step.[13] Two user-defined priority systems determine allocations of water supplies to demands (i.e. urban and agricultural), for IFRs, and for filling reservoirs—demand priorities and supply preferences.

Demand priorities are used to allocate water to competing demand sites and catchments, flow requirements, and reservoir storages. The *demand priority* is attached to the demand site, catchment, reservoir, or flow requirement and ranges from 1 to 99, with 1 being the highest priority and 99 the lowest. Many demand sites can share the same priority, which is useful in representing a system of water rights, where water users are defined by their water usage and/or seniority. In cases of water shortage, higher priority users are satisfied as fully as possible before lower priority users are considered. If priorities are the same, shortage will be shared equally (as a percentage of demand).

SacWAM uses several general categories of demand to define the system of priorities. In general, the highest priority is assigned to operations (water storage and delivery) in the upper watersheds. Sacramento Valley water users have the next highest priority level and water users relying on Delta exports have the lowest priority level. Within the Sacramento Valley, water users are further distinguished by their demand type (i.e. urban, agriculture, refuge, or flow requirement) and contract type (i.e. Non-Project, CVP, or SWP). The general demand priority structure of SacWAM is set up in WEAP's Data Tree under *Other Assumptions\Ops\Priorities*. Each demand within SacWAM then references the appropriate sub-branch within this structure. This demand structure is also presented in Table 7-29.

[13] It is important to note that while WEAP uses an LP to allocate water, it is not an optimization tool. It allocates water hierarchically to demands with the highest priority at each time step. It does not consider how water is allocated across multiple time steps.

Table 7-29. General Priority Structure of Demands in SacWAM

SacWAM Demand Group	Demand Priority
Upper Watershed Reservoirs	5
Upper Watershed Demand	6
Upper Watershed Diversions	7
SWRCB IFRs	8
Non Project Tributary Demands	10
Non Project Tributary IFR	11
Non Project Tributary Storage	12
Agriculture Non Project	13
Urban Non Project	13
Los Vaqueros	14
CVP Settlement Contractors	17
SWP Settlement Contractors	17
Project Tributary IFR	22
Required Delta Outflow	27
CVP Refuge Contractors	35
CVP Urban Contractors	37
CVP Ag Contractors	39
CVP SOD Canal Losses	40
CVP SOD Exchange Contractors	41
CVP SOD Refuge Contractors	42
CVP SOD Urban Contractors	43
CVP SOD Ag Contractors	44
CVP SOD Storage	45
CVP NOD Storage	46
SWP Canal Losses	50
SWP Contractors	51
SWP NOD Storage	52
SWP SOD Storage	52
Fill CVP San Luis	55
Fill SWP San Luis	60
Bypass Demand	63
CVP Cross Valley Canal	99
Routing IFR	99

Key: CVP=Central Valley Project; IFR=instream flow requirement; NOD=north of Delta; SOD=south of Delta; SWP=State Water Project; SWRCB=State Water Resources Control Board.

7.2.5 Delta Channels

This section describes the operation of the structures that control flows through the Delta Cross-Channel (DXC) gates and from the San Joaquin River into the Head of the Old River (HOR).

7.2.5.1 *DXC*

DXC diverts flows from the main channel of the Sacramento River into the north branch of the Mokelumne River at Walnut Grove. The DXC and its head gates are a feature of Reclamation's CVP and are intended to maintain water quality for transfers from CVP reservoirs north of the Delta to the headworks of the DMC and Contra Costa canal.

The DXC gates are operated in accordance with SWRCB Decision 1641 (SWRCB, 1999), which specifies periods during which the gates should be closed to support fisheries protection. For modeling purposes, we use a lookup table that fixes the number of days in a month that the DXC gates are open (*DXC_days*, Table 7-30).

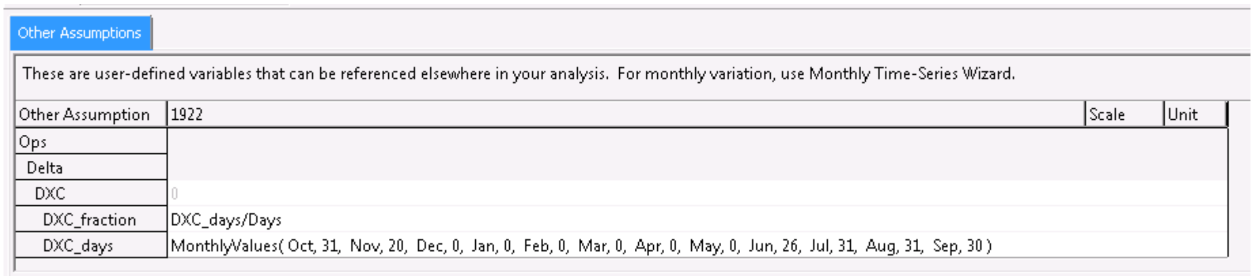


Table 7-30. Number of Days Delta Cross Channel Gates Are Open

Month	Number of Days Open
October	31
November	20
December	0
January	0
February	0
March	0
April	0
May	0
June	26
July	31
August	31
September	30

Thus, we can use the following expression in WEAP to estimate the fraction of the month that the DXC gates are open (*DXC_fraction*):

Equation 7-1 Fraction of Month DXC Gates Are Open

DXC_fraction=MonthlyValues(Oct, 31, Nov, 20, Dec, 16, Jan, 11, Feb, 0, Mar, 0, Apr, 0, May, 0, Jun, 26, Jul, 31, Aug, 31, Sep, 30) / Days

For an explanation of DXC operations, UDCs, and their associated parameters, see Section 8.5.

7.2.5.2 South Delta

Head of Old River

Flows at HOR are expressed as a function of San Joaquin River flows at Vernalis using the following equation:

$$Q_{HOR} = C1 * Q_{Vernalis} + C2$$

Values for C1 and C2 vary depending upon time of year and level of flows at Vernalis. These are summarized in Table 7-31.

Table 7-31. Coefficients Used to Set Flows at Head of Old River

Condition	C1	C2
June, July, August	0.419	-26
April, May AND $Q_{Vernalis}$ < 5,000 cfs	0.079	69
October, November AND $Q_{Vernalis}$ < 5,000 cfs	0.238	-51
$Q_{Vernalis}$ < 16,000 cfs	0.471	83
16,000 cfs < $Q_{Vernalis}$ < 28,000 cfs	0.681	-3008
$Q_{Vernalis}$ > 28,000 cfs	0.633	-1644

SacWAM uses a diversion object to take water off of the San Joaquin River into the Old River. Flows into this diversion are set using the *Fraction Diverted* parameter associated with the diversion model object, which is entered as a percentage of river flow above the diversion. This parameter references the branch of the Data Tree *Other\Ops\Delta\South Delta\Head of Old River\Percent_SJ_to_HOR,* which is defined as Q_{HOR} / $Q_{Vernalis}$.

7.2.6 Delta Salinity

This section describes the routines that are used to calculate flow requirements needed to satisfy X2 and D-1641 water quality standards within the Delta.

SacWAM offers two methods for computing Delta outflow requirements for salinity control: the G-model and Artificial Neural Network (ANN). Both options compute Delta outflow requirements using external functions called from SacWAM. They are described in separate sections below. Only one option can be selected when the model is run. The default option selects ANN to compute Delta salinity.

7.2.6.1 *X2*

The X2 operation rule exists to address the salinity requirement. The X2 standard is expressed in terms of the location of the 2 parts per thousand bottom isohaline as measured in kilometers upstream from the Golden Gate Bridge. SacWAM offers two methods to compute the net Delta outflow required to meet this standard. It can either call the same Delta ANN used to compute other salinity compliance or it can use the Kimmerer-Monismith equation (Jassby et al., 1995). Either approach can be selected by changing the value of the Other\Ops\Delta\X2\UseANN (where a value of 1 indicates SacWAM will use ANN and a value of 0 indicates that SacWAM will use the Kimmerer-Monismith equation). The default approach is to use ANN.

7.2.6.2 *GMOD*

Outflow requirements to meet Delta salinity standards may be determined by linking SacWAM to Contra Costa WD's salinity-outflow model, commonly referred to as the "G-model" (Denton and Sullivan, 1993). The G-model is based on a set of empirical equations, developed from the one-dimensional advection-dispersion equation. The G-model predicts salinity caused by seawater intrusion at a number of key locations in Suisun Bay and the western Delta as a function of antecedent Delta outflow. The antecedent Delta outflow is a surrogate for directly modeling salinity distribution within the Delta and incorporates the combined effect of all previous Delta outflows. That is, the G-model assumes that salinity is a function of both current outflow and outflows from the previous 3 to 6 months. Because this salinity-outflow model was developed from the one-dimensional advection-dispersion equation, it accounts for the transport of salt by both mean flow (advection) and tidal mixing (dispersion).

One limitation of the G-model is that the equations were developed under current sea level conditions. As such, SacWAM includes an alternative method for setting Delta flows to meet salinity standards (i.e. the Delta *ANN*), which is discussed in the next section. This model has been trained to handle four sea level rise scenarios (1-foot rise, 2- foot rise, 1-foot rise plus 4-inch amplitude increase, and 2-foot rise plus 4-inch amplitude increase).

7.2.6.3 *ANN*

In addition to the G-model, SacWAM also includes an option to use an ANN, developed by DWR for CalSim II, to calculate Delta salinity and outflow requirements. The switch to activate ANN is discussed in Section 7.8.

The ANN was developed by DWR in an attempt to integrate into CalSim II model a faithful representation of the flow-salinity relationships as modeled by the Delta Simulation Model (DSM2). These relationships were then used by CalSim II to set Sacramento River flow targets and export limits in order to meet salinity standards at various locations in the Delta. The ANN also determines salinity (micro-mhos/cm) at these locations given estimates of Delta inflows, outflows, and exports and the position of Delta cross-channel. It is described in more detail in several DWR reports (Finch and Sandhu 1995; DWR, 2000b; Hutton and Seneviratne, 2001; Wilbur and Munevar, 2001; Mierzwa, 2002; Seneviratne, 2002; and Smith, 2008)[14].

The basic formulation of the ANN has remained the same for some years and still relies upon the same set of modeled inputs as noted by Wilbur and Munevar (2001), who pointed out that the ANN

> *predicts salinity at various locations in the Delta using the following parameters as input: Sacramento River inflow, San Joaquin River inflow, Delta Cross Channel gate position, and total exports and diversions. Sacramento River inflow includes Sacramento River flow, Yolo Bypass flow, and combined flow from the Mokelumne, Cosumnes, and Calaveras rivers (East Side Streams). Total exports and diversions include State Water Project (SWP)*

[14] At the time of this writing these reports were all available for download at http://modeling.water.ca.gov/delta/models/ann/index.html

> *Banks Pumping Plant, Central Valley Project (CVP) Tracy Pumping Plant, North Bay Aqueduct exports, Contra Costa Water District diversions, and net channel depletions. A total of 148 days of values of each of these parameters is included in the correlation, representing an estimate of the length of memory in the Delta.*

The ANN itself is configured as a Fortran-compiled Dynamic-Link Library (DLL) that contains several functions. These functions include routines for calculating the EC at various locations for previous time steps and for calculating the parameters used in equations to set flow targets and export constraints. The ANN has been updated several times since its first introduction. The ANN included with SacWAM is taken from the existing conditions study included within the 2015 SWP Delivery Capability Report (DWR, 2015).

For the purposes of linking WEAP to the ANN it was necessary to recompile the DLL such that it could be called from WEAP. This required creating new functions within the DLL that received from WEAP a single double precision array of values, rather than several individual real and integer values as it is done with CalSim. To do this, we wrote Fortran code that created new functions callable from WEAP that are essentially "wrappers" to the existing DLL functions. The DLL functions that are used in the PA model are:

- ANNECARRAY which calculates the salinity from the previous month at different stations within the Delta
- ANNEC_MATCHDSM2ARRAY which calculates the salinity from 2 months prior at different stations within the Delta
- ANNLINEGENARRAY which calculates the slope and intercept of the linear equation that is used to constrain Delta exports as a function of inflows from the Sacramento River and Yolo Bypass

To access these routines within the DLL, WEAP uses a 'Call' function which takes the following form: Call(DLLFileName ! DLLFunctionName, parameter1, parameter2, ...). Where there is only one DLLFileName (e.g. Ann7inp_ROA0SLR0cm_SA.dll) for every call to the DLL; the DLLFunctionName was one of the three functions listed above; and the parameters differ between the three functions and are listed in Table 7-32, Table 7-33, and Table 7-34.

It should be noted here that in both CalSim II and SacWAM only the last function (AnnLineGen in CalSim and AnnLineGenArray in SacWAM) is needed to set flow targets and export constraints. The other two functions are called only to report the estimated Delta water quality from the previous months.

Table 7-32. List of Parameters for ANN Function AnnECArray

Parameter Number	Description	Parameter(s)
1-5	Sacramento River flows at Hood over previous 5 months	C400_5, C400_4, C400_3, C400_2, C400_1
6-10	CVP and SWP Delta Exports over previous 5 months	D409_5, D409_4, D409_3, D409_2, D409_1
11-15	San Joaquin River flows at Vernalis over previous 5 months	C639_5, C639_4, C639_3, C639_2, C639_1
16-20	Number of days the delta cross channel gates are open for each of the previous 5 months	DXC_5, DXC_4, DXC_3, DXC_2, DXC_1
21-25	Net in-Delta consumptive use over previous 5 months	net_DICU_5, net_DICU_4, net_DICU_3, net_DICU_2, net_DICU_1
26-30	Other Sacramento River Basin inflows to the Delta over previous 5 months	sac_oth_5, sac_oth_4, sac_oth_3, sac_oth_2, sac_oth_1
31-35	Other Delta Exports over previous 5 months	exp_oth_5, exp_oth_4, exp_oth_3, exp_oth_2, exp_oth_1
36-40	San Joaquin River water quality at Vernalis over previous 5 months	VernWQFinal_5, VernWQFinal_4, VernWQFinal_3, VernWQFinal_2, VernWQFinal_1
41-45	Number of days in the month over previous 5 months	daysin_5, daysin_4, daysin_3, daysin_2, daysin_1
46	Station identifier[1]	Jersey Point (JP) = 1, Rock Slough (RS) = 2 Emmaton (EM) = 3, Collinsville (CO) = 5
47	Average type[2]	Monthly average = 1 Maximum 14-day value = 6
48	Previous month index	Mo = 12 if October Otherwise, Mo = TS-1
49	Previous month water year	Year = Water Year - 1 if October, Otherwise, Year = Water Year

Notes:
[1] The ANN functions were developed to consider twelve different stations. However, only four are used.
[2] The average type is used for the functions that return estimates of water quality - i.e. AnnECArray and AnnEC_matchDSM2Array. There are eight different types of averages that the can be calculated by various functions within the DLL. Only two are used in both CalSim II and WEAP.
Key: CVP=Central Valley Plan; SWP=State Water Plan.

Table 7-33. List of Parameters for ANN Function AnnEC_matchDSM2Array

Parameter Number	Description	Parameter(s)
1-7	Sacramento River flows at Hood over previous 7 months	C400_7, C400_6, C400_5, C400_4, C400_3, C400_2, C400_1
8-12	CVP and SWP Delta Exports over previous 2 to 6 months	D409_6, D409_5, D409_4, D409_3, D409_2
13-19	San Joaquin River flows at Vernalis over previous 7 months	C639_7, C639_6, C639_5, C639_4, C639_3, C639_2, C639_1
20-24	Number of days the delta cross channel gates are open for each of the previous 2 to 6 months	DXC_6, DXC_5, DXC_4, DXC_3, DXC_2
25-29	Net in-Delta consumptive use over previous 2 to 6 months	net_DICU_6, net_DICU_5, net_DICU_4, net_DICU_3, net_DICU_2
30-34	Other Sacramento River Basin inflows to the Delta over previous 2 to 6 months	sac_oth_6, sac_oth_5, sac_oth_4, sac_oth_3, sac_oth_2
34-39	Other Delta Exports over previous 2 to 6 months	exp_oth_6, exp_oth_5, exp_oth_4, exp_oth_3, exp_oth_2
40-44	San Joaquin River water quality at Vernalis over previous 2 to 6 months	VernWQFinal_6, VernWQFinal_5, VernWQFinal_4, VernWQFinal_3, VernWQFinal_2
45-51	Number of days in the month over previous 7 months	daysin_7, daysin_6, daysin_5, daysin_4, daysin_3, daysin_2, daysin_1
52	Station identifier[1]	Jersey Point (JP) = 1, Rock Slough (RS) = 2 Emmaton (EM) = 3, Collinsville (CO) = 5
53	Average type[2]	Monthly average = 1 Maximum 14-day value = 6
54	Index for 2 months prior	Mo = 11 if October Mo = 12 if November Otherwise, Mo = TS-2
55	Water year for 2 months prior	Year = Water Year - 1 if October or November, Otherwise, Year = Water Year

[1] The ANN functions were developed to consider twelve different stations. However, only four are used.
[2] The average type is used for the functions that return estimates of water quality - i.e. AnnECArray and AnnEC_matchDSM2Array. There are eight different types of averages that the can be calculated by various functions within the DLL. Only two are used in both CalSim II and WEAP.
Key: CVP=Central Valley Plan; SWP=State Water Plan.

Table 7-34. List of Parameters for ANN Function AnnLineGenArray

Parameter Number	Description	Parameter(s)
1-4	Sacramento River flows at Hood over previous 4 months	C400_4, C400_3, C400_2, C400_1
5-8	CVP and SWP Delta Exports over previous 4 months	D409_4, D409_3, D409_2, D409_1
9-12	San Joaquin River flows at Vernalis over previous 4 months	C639_4, C639_3, C639_2, C639_1
13	Estimate of current month's San Joaquin River flows at Vernalis	SJR_ann_est
14-17	Number of days the delta cross channel gates are open for each of the previous 4 months	DXC_4, DXC_3, DXC_2, DXC_1
18	Estimate of current month's number of days with delta cross channel gates open	DXC_est
19-22	Net in-Delta consumptive use over previous 4 months	net_DICU_4, net_DICU_3, net_DICU_2, net_DICU_1
23	Estimate of current month's net in-Delta consumptive use	Net_delta_cu
24-27	Other Sacramento River Basin inflows to the Delta over previous 4 months	sac_oth_4, sac_oth_3, sac_oth_2, sac_oth_1
28	Estimate of current month's inflow to Delta from other Sacramento River Basin sources	sac_oth_est
29-32	Other Delta Exports over previous 4 months	exp_oth_4, exp_oth_3, exp_oth_2, exp_oth_1
33	Estimate of current month's other Delta Exports	exp_oth_est
34-37	San Joaquin River water quality at Vernalis over previous 4 months	VernWQFinal_4, VernWQFinal_3, VernWQFinal_2, VernWQFinal_1
38	Estimate of current month's San Joaquin River water quality at Vernalis	VernWQFinal_est
39-42	Number of days in the month over previous 4 months	daysin_4, daysin_3, daysin_2, daysin_1
43	Number of days in current month	daysin
44	Water quality standards	Water year dependent, monthly varying EC standards at Jersey Point, Rock Slough, Emmaton, and Collinsville
45	Lower bound for linearization of export constraint[1]	JP_line_lo, CO_line_lo, EM_line_lo, RS_line_1_lo, RS_line_2_lo, RS_line_3_lo
46	Upper bound for linearization of export constraint[1]	JP_line_hi, CO_line_hi, EM_line_hi, RS_line_1_hi, RS_line_2_hi, RS_line_3_hi
47	Station identifier[2]	Jersey Point (JP) = 1 Rock Slough (RS) = 2 Emmaton (EM) = 3 Collinsville (CO) = 5
48	Constant type[3]	Slope = 1 Intercept = 2
49	ANN type[4]	Value = 1
50	Previous month index	Mo = 12 if October Otherwise, Mo = TS-1
51	Previous month water year	Year = Water Year - 1 if October, Otherwise, Year = Water Year
52	Other Parameter	Value = 1 for RS linearization #1 Value = 2 for RS linearization #2 Value = 3 for RS linearization #3 Value = 4 for JP, CO, and EM

Notes:
[1] Parameters and associated values derived directly from CalSim model inputs
[2] The ANN functions were developed to consider twelve different stations. However, only four are used.
[3] The constant type is used for the function (i.e. AnnLinGenArray) that returns to WEAP the constants that are used in equations that constrain Delta exports based on Sacramento River and Yolo Bypass flows.

Key: CVP=Central Valley Plan; SWP=State Water Project.

Each of the ANN input parameters listed in Table 7-32, Table 7-33, and Table 7-34 were added as user-defined variables within SacWAM. These were added into WEAP's data tree structure under Other Assumptions. Specifically, they were added under the branch *Other\Ops\Delta\ANN*. The WEAP expressions used to calculate values for these are shown in Table 7-35, where we show expressions only for calculating the previous month's values. This is easily and logically extended to earlier months using WEAP's PrevTSValue function.

Most of these ANN input parameters were easily calculated using SacWAM. However, the San Joaquin River flows at Vernalis and its water quality, *VernWQFinal*, posed a particular challenge because the model does not cover the region from which these flows originate. Instead, we used timeseries of flows obtained from Phase 1 of the Bay-Delta Plan and timeseries of water quality estimates obtained from CalSim II.[15]

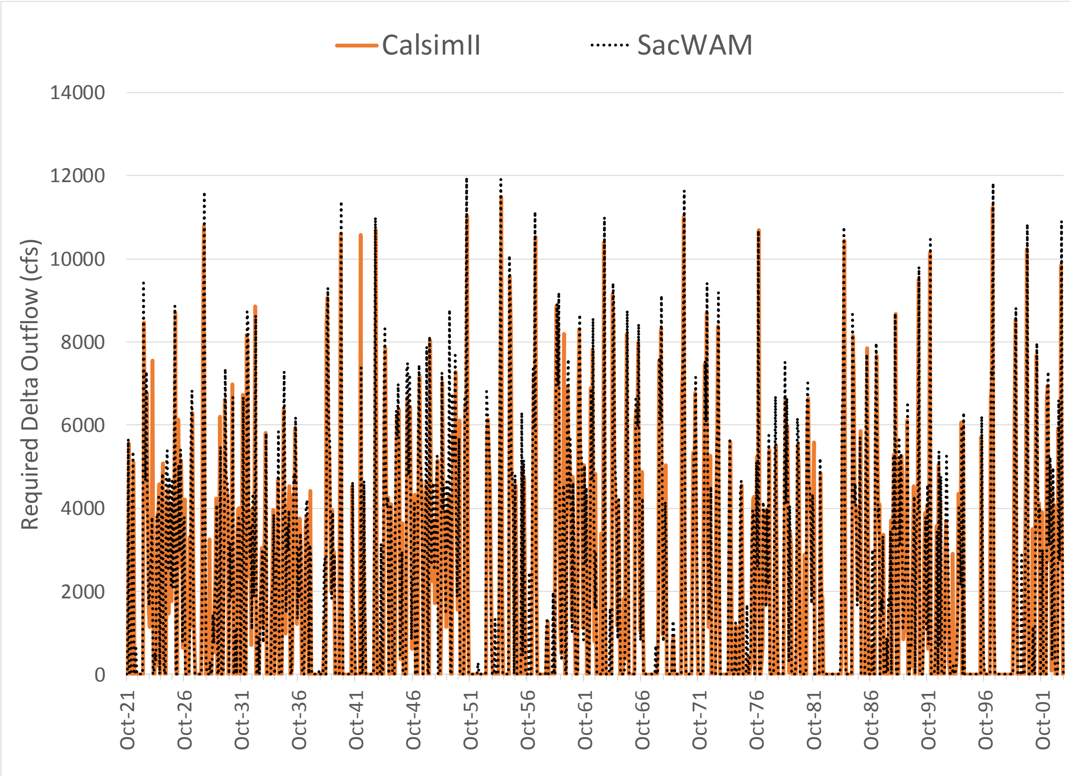
To check that SacWAM is both passing data to the ANN and returning values correctly, ANN results from SacWAM and CalSim II were compared for the same set of flow-based inputs. The model results for previous month salinity at compliance locations matched. However, there were minor differences in the required Delta outflow for salinity control as shown in Figure 7-2.   The reasons for these discrepancies has not been identified.

[15] Based on a 1921-2003 CalSim II simulation of existing condition (1_DCR2015_Base_ExistingNoCC) from DWR's 2015 SWP Delivery Capability Report.

Table 7-35. WEAP Parameters Used as Input to Delta ANN

ANN Input Parameter	Description	WEAP Expression Used to Calculate Parameter Value
C400_1	Previous month's Sacramento River flows at Hood	PrevTSValue(Supply and Resources\River\Sacramento River\Reaches\Below SAC to PA510_outdoor:Streamflow[CFS])
D409_1	Previous month's combined CVP pumping at Jones and SWP pumping at Banks	PrevTSValue(Supply and Resources\River\Delta Mendota Canal\Reaches\Below Delta Mendota Canal Diverted Inflow:Streamflow[CFS]) +~PrevTSValue(Supply and Resources\River\California Aqueduct\Reaches\Below California Aqueduct Diverted Inflow:Streamflow[CFS])
C639_1	Previous month's San Joaquin River flows at Vernalis	PrevTSValue(Supply and Resources\River\San Joaquin River\Reaches\Below Vernalis:Streamflow[CFS])
DXC_1	Previous month's number of days with delta cross channel open	If(C400>25000, 0, 1) * MonthlyValues(Oct, 31, Nov, 20, Dec, 16, Jan, 11, Feb, 0, Mar, 0, Apr, 0, May, 0, Jun, 26, Jul, 31, Aug, 31, Sep, 30)
Net_DICU_1	Previous month's net in-Delta consumptive use	PrevTSValue(Demand Sites and Catchments\PA510:Water Demand[CFS]) + PrevTSValue(Demand Sites and Catchments\PA602_North:Water Demand[CFS]) -PrevTSValue(Demand Sites and Catchments\PA510:Interflow[CFS]) - PrevTSValue(Demand Sites and Catchments\PA510:Base Flow[CFS]) - PrevTSValue(Demand Sites and Catchments\PA602_North:Interflow[CFS]) - PrevTSValue(Demand Sites and Catchments\PA602_North:Base Flow[CFS])
Sac_oth_1	Previous month's other Sacramento River Basin inflows to the Delta	PrevTSValue(Supply and Resources\River\Yolo Bypass\Reaches\Below Yolo Bypass to PA510:Streamflow[CFS]) +PrevTSValue(Supply and Resources\River\Mokelumne River\Reaches\Below Cosumnes River Inflow:Streamflow[CFS]) +PrevTSValue(Supply and Resources\River\Calaveras River\Reaches\Below CAL to PA603S PA603_indoor PA602_indoor:Streamflow[CFS])
Exp_oth_1	Previous month's other exports from the Delta	PrevTSValue(Supply and Resources\Transmission Links\to PA601andCC_Indoor\from SAC to PA601andCC_Indoor:Flow[CFS]) + 0.1 * PrevTSValue(Supply and Resources\Transmission Links\to PA602_North\from SJR to PA602N:Flow[CFS])
VernWQFinal_1	Previous month's San Joaquin River water quality at Vernalis	If(Other\Ops\Environmental Requirements\SacWYT = 1, MonthlyValues(Oct, 508, Nov, 582, Dec, 704, Jan, 600, Feb, 457, Mar, 387, Apr, 296, May, 292, Jun, 405, Jul, 499, Aug, 451, Sep, 459), Other\Ops\Environmental Requirements\SacWYT = 2, MonthlyValues(Oct, 581, Nov, 667, Dec, 815, Jan, 740, Feb, 678, Mar, 555, Apr, 383, May, 390, Jun, 498, Jul, 601, Aug, 548, Sep, 542), Other\Ops\Environmental Requirements\SacWYT = 3, MonthlyValues(Oct, 550, Nov, 622, Dec, 790, Jan, 785, Feb, 670, Mar, 671, Apr, 407, May, 415, Jun, 568, Jul, 633, Aug, 566, Sep, 567), Other\Ops\Environmental Requirements\SacWYT = 4, MonthlyValues(Oct, 541, Nov, 628, Dec, 834, Jan, 854, Feb, 908, Mar, 904, Apr, 483, May, 514, Jun, 634, Jul, 646, Aug, 611, Sep, 598), MonthlyValues(Oct, 611, Nov, 667, Dec, 877, Jan, 903, Feb, 947, Mar, 951, Apr, 580, May, 594, Jun, 648, Jul, 647, Aug, 664, Sep, 654))

Key: CVP=Central Valley Plan; SWP=State Water Plan.



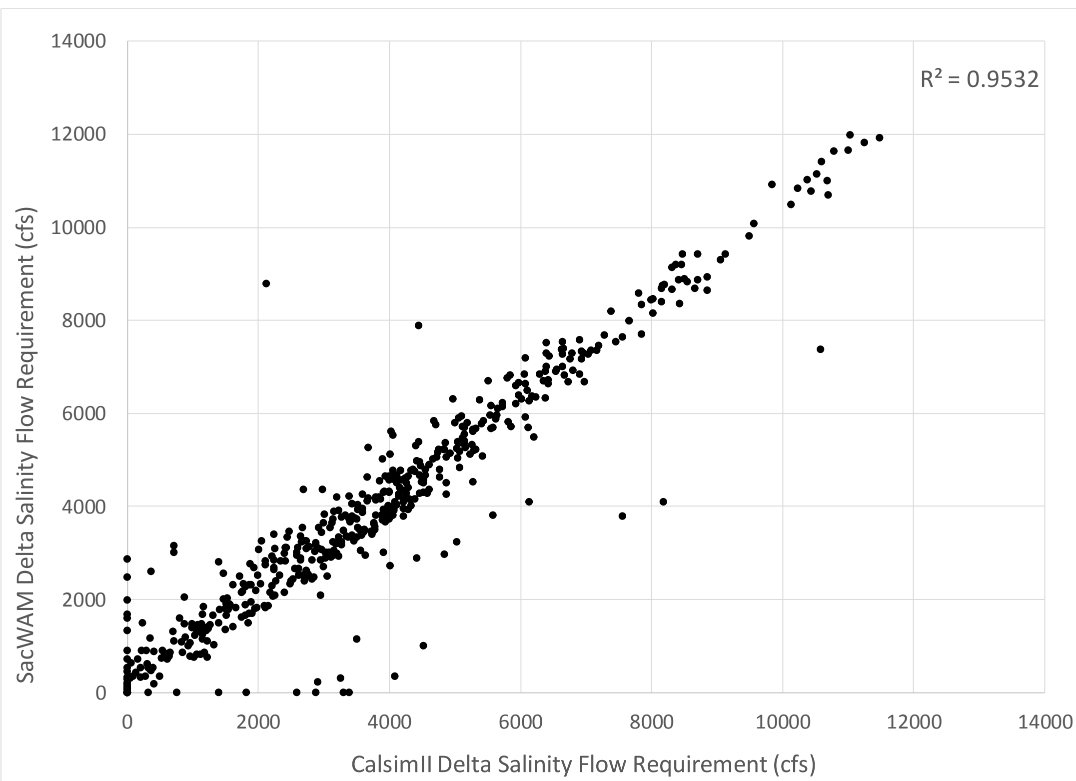


Figure 7-2. Required Delta Outflow for Salinity Control as Simulated by CalSim II and SacWAM

To use the ANN to calculate Delta salinity flow requirements, SacWAM must provide the ANN estimates of current time step values for each of the parameters listed in Table 7-34 except the first two, i.e. Sacramento River flows at Hood and combined CVP and SWP pumping from the Delta. To estimate these values, we used a statistical approach that used a baseline SacWAM run from 1950 to 2005 to derive flow estimates. The development of these estimates is described below.

The implementation of the ANN to enforce water quality standards is set up in SacWAM in *User Defined LP Constraints*. For information about these constraints, see Section 8.7.

Net in-Delta Consumptive Use

SacWAM estimates the current month's net in-Delta consumptive use using average monthly values derived from a 1950-2005 WEAP baseline simulation (Table 7-36). The agreement of this estimation (*net_Delta_cu_est*) with simulated values of net in-Delta consumptive use (*net_DICU*) are shown in Figure 7-3.

Table 7-36. Simulated Average Monthly Net in-Delta Consumptive Use by Water-Year Type

Sacramento Valley Water-Year Type	Average Monthly Flow 1950-2005 (cfs)											
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Wet	208	266	(358)	(499)	(306)	104	870	1,902	3,500	2,917	2,861	514
AboveNormal	195	338	(277)	(467)	(362)	123	1,149	1,804	3,582	2,966	2,871	536
BelowNormal	422	444	(144)	(215)	(75)	601	1,611	2,415	3,676	2,957	2,890	516
Dry	259	387	(149)	(193)	149	626	1,537	2,370	3,665	2,982	2,871	505
Critical	204	452	(71)	(44)	162	739	1,537	2,097	3,573	2,978	2,893	531

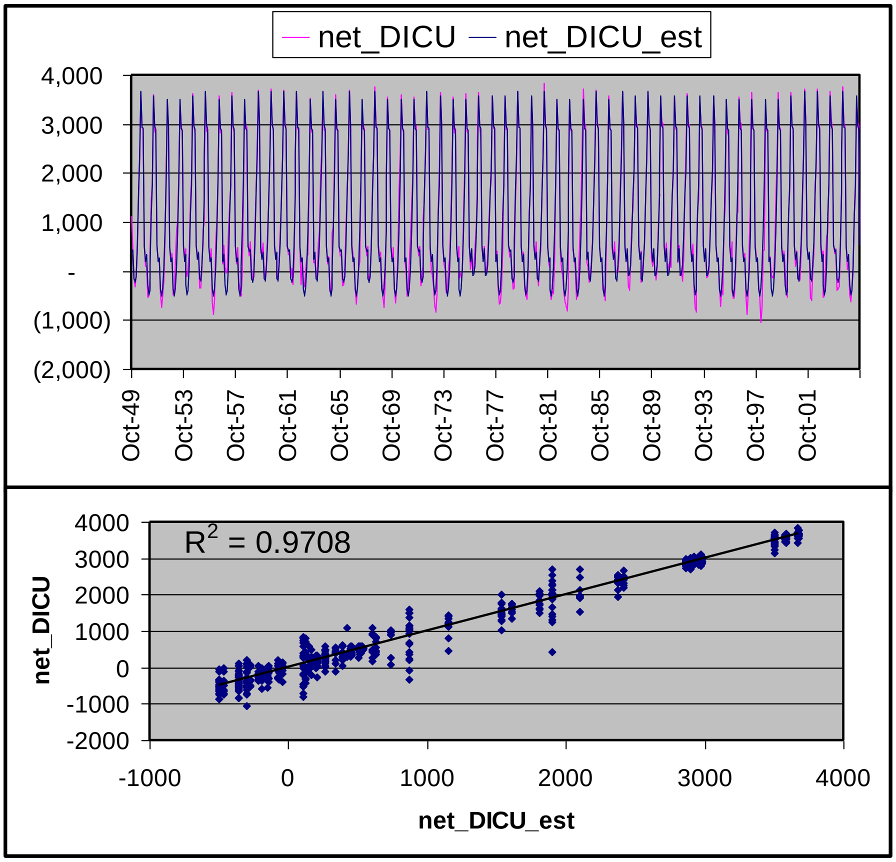


Figure 7-3. Statistical Estimation of In-Delta Net Consumptive Use

Other Delta Exports

The current month's other Delta exports are estimated by the following equation:

exp_oth_est = 0.90 * average monthly 'other exports' +
(1 - 0.90) * previous month's 'other exports' * monthly perturbation

where the monthly perturbation is the ratio of average current month's other exports over the average of the previous month's other exports and is shown with the average monthly other exports in Table 7-37. The agreement of this estimation (*exp_oth_est*) with simulated values of other exports (*exp_oth*) are shown in Figure 7-4.

Table 7-37. Simulated Average Monthly Other Delta Exports

Sacramento Valley	Average Monthly Flow 1950-2005 (cfs)											
Water-Year Type	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Wet	238	262	231	231	231	253	294	347	429	391	375	249
AboveNormal	238	263	231	231	231	251	308	336	433	393	375	249
BelowNormal	241	266	232	231	231	267	328	367	436	392	376	249
Dry	238	265	232	231	234	270	325	366	436	393	375	249
Critical	238	266	232	232	234	274	325	351	432	393	376	249
Monthly Pertubation	0.96	1.11	0.88	1.00	1.01	1.13	1.20	1.12	1.23	0.91	0.96	0.66

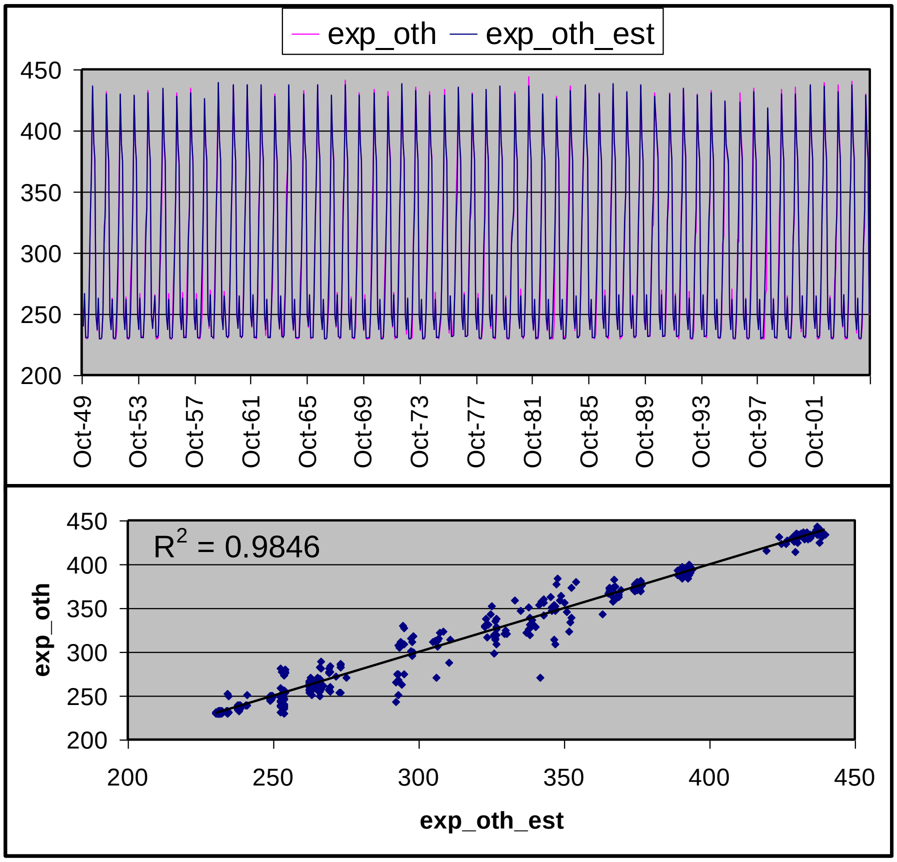


Figure 7-4. Statistical Estimation of Other Delta Exports

Other Sacramento River Basin Inflows to the Delta

The current month's other Sacramento River basin inflows to the Delta is estimated by the following equation:

sac_oth_est = 0.75 * average monthly (Mokelumne+Cosumnes+Calaveras) inflows +
(1 - 0.75) * previous month's Mok+Cos+Cal inflows * monthly perturbation +
average monthly Yolo Bypass inflows

where the monthly perturbation is the ratio of average current month's inflows over the average of the previous month's combined inflows and is shown with the average monthly values in Table 7-38. Average monthly Yolo Bypass inflows are shown in Figure 7-5.

The agreement of this estimation (*sac_oth_est*) with baseline simulated valued (*sac_oth*) is shown in Figure 7-5.

Table 7-38. Simulated Average Monthly Eastside Streams Inflows to the Delta

Sacramento Valley Water-Year Type	Average Monthly Flow 1950-2005 (cfs)											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Wet	980	688	2,619	6,052	7,078	6,371	4,773	2,897	863	474	363	681
AboveNormal	1,523	1,229	3,029	3,554	5,404	3,625	2,570	1,507	676	438	360	555
BelowNormal	937	562	1,159	1,804	2,362	2,080	2,318	1,175	550	344	270	387
Dry	1,329	640	1,091	1,437	2,054	1,821	1,182	740	439	320	275	391
Critical	1,129	355	401	552	843	1,195	1,029	560	357	240	197	195
Monthly Pertubation	2.67	0.59	2.39	1.61	1.32	0.85	0.79	0.58	0.42	0.63	0.81	1.51

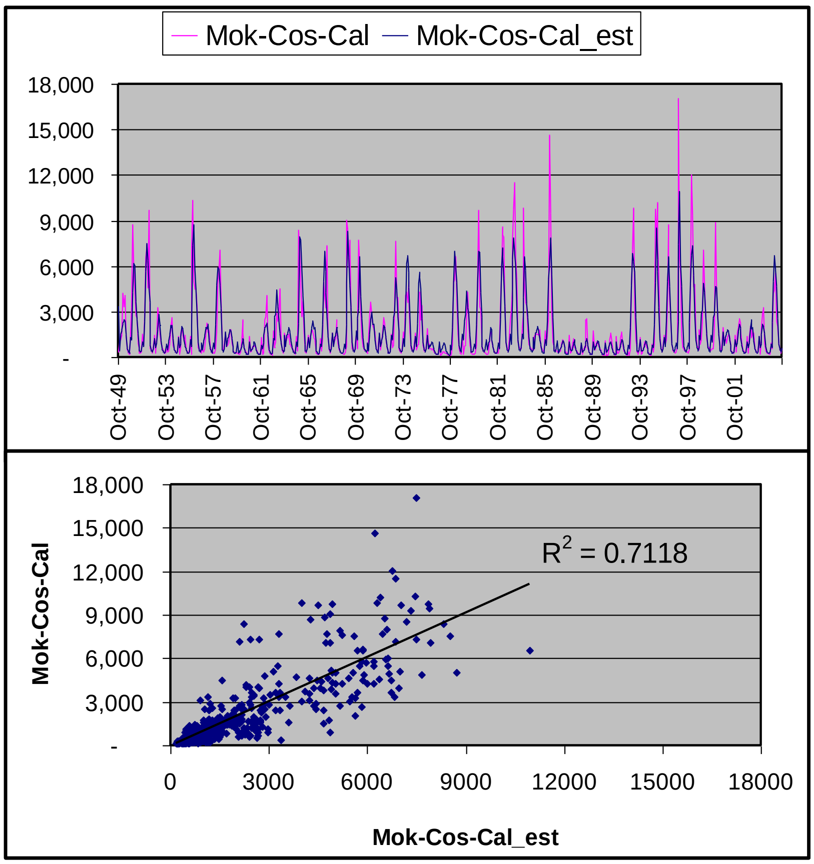


Figure 7-5. Statistical Estimation of Combined Mokelumne-Cosumnes-Calaveras River Inflows to the Delta

Delta Cross Channel Gates

Within the current time step, SacWAM uses the Bay-Delta Plan (SWRCB, 1995) monthly varying estimate of the number of days that the gates are open (Table 7-39), which was taken from the CalSim II model.

Table 7-39. Days Open for Delta Cross-Channel Gate

Month	Number of Days Open
October	31
November	20
December	16
January	11
February	0
March	0
April	0
May	0
June	26
July	31
August	31
September	30

7.2.7 Hydrologic Indices

SacWAM contains routines for tracking hydrologic indices for different watersheds within the Sacramento and San Joaquin River basins. These indices are used within the model to adjust environmental flow requirements and to guide curtailment of deliveries to CVP and SWP water contractors.

SacWAM offers two methods for determining hydrologic indices: (1) read in historical values from an external file or (2) estimate indices using WEAP's hydrologic module. The first method is used when the model is run with fixed timeseries of historical inflows. In this case, annual values are read in for the historical period 1922-2009. The second method is used when WEAP hydrologic routines are used to estimate runoff. While this method may introduce some error because it relies on forecasting flows with imperfect information, it allows the model to be run under climatic conditions that are different from the historical record.

When the hydrologic routines are used in SacWAM, annual water yields are estimated in the winter and early spring (Feb-May) so that water allocations may be adjusted to match estimates of available water supply for the year. Threshold criteria are applied to these water yield estimates to determine water-year types (WYTs), which influence both water allocations and environmental flow standards.

Annual water yields are estimated using a combination of cumulative runoff since the beginning of the water year and runoff forecasts for the remainder of the water year. Cumulative runoff is simply the sum of the simulated unimpaired flows (i.e. runoff from all upstream catchments) since October 1st. Runoff forecasts are estimated using regression equations that are based on a combination of simulated snowpack and cumulative runoff as the independent variables. Regression equations were developed for each month February through May to estimate runoff through the remainder of the water year. These regression equations took the following form:

$$\sum_{t}^{t=12} Q_t = C_1 + C_2 \sum_{t=1}^{t-1} Q_t + C_3 S_{t-1}$$

where t is the water-year month (i.e. t=1 in October and t=12 in September), Q_t is the runoff at some location, S_{t-1} is the snowpack at the end of the previous month, and C_1, C_2, and C_3 are the regression coefficients.[16]

The sections below summarize the results of applying this approach to estimate runoff forecasts for several locations: Trinity River at Lewiston, Sacramento River at Lake Shasta, Sacramento River at Bend Bridge, Feather River at Oroville, Yuba River at Smartville, American River at Folsom Lake, and Mokelumne River at Pardee.

Some general trends were observed. First, the correlation between runoff forecasts and the simulated runoff are poor at the beginning of the process (February) and become stronger as we move into spring (April-May). This is largely due to the fact that the two independent variables that we are using —i.e. October-January runoff and end-of-January snowpack—are poor indicators of water-year hydrology; there is too much uncertainty this early in the water year.

Another thing to note is that higher correlations between snowpack and runoff result in more reliable estimates of runoff forecasts. This implies two things. First, in locations where there is a strong correlation to snowpack, the regression equations tend to weight the snowpack more heavily in April and May. Second, these correlations are stronger in high-elevation watersheds that have hydrographs dominated by spring snowmelt. Thus, the correlations tend to become stronger as we move south in the Sierra watersheds.

7.2.7.1 *Trinity*

Trinity River WYTs (Table 7-40) are based on the total annual (October-September) water yield upstream from Lewiston Dam. Five water-year classes are defined based on the Trinity *Index* (*CumInflow* + *Runoff Forecast*) for the Trinity River under *Ops\Hydrologic Indices\Trinity* (USFWS and Hoopa Valley Tribe, 1999).

Table 7-40. Trinity River Water-Year Classifications

Water-Year Class	Annual Water Yield (TAF)	Code in WEAP
Extremely Wet	>= 2000	1
Wet	1350 to 2000	2
Normal	1025 to 1350	3
Dry	650 to 1025	4
Critically Dry	< 650	5

CumInflow

The cumulative inflow consists of the total cumulative flow to the river of the upstream catchments since the beginning of the water year (October 1) adjusted by the *Simulate Hydrology* parameter (see Section 9.4).

[16] Note that in the case of estimating runoff forecasts for the Sacramento River at Bend Bridge, we use snowpack values from four separate upstream watersheds: Upper Sacramento River, Pitt River, Clear Creek, and Cottonwood Creek. Thus, this equation is expanded to include six regression coefficients.

Runoff Forecast

Table 7-41 shows the regression coefficients (*Runoff Forecast\C1*, *C2*, and *C3*) that are used in estimating runoff forecasts for the Trinity River at Lewiston (*Runoff Forecast*). These calculations relied on snowpack from one upstream catchment (*Runoff Forecast\Snowpack*).

Table 7-41. Regression Coefficients Used to Forecast Runoff for Trinity River

Regression Coefficient	February	March	April	May
C1	404.2974	131.6744	41.8316	53.1807
C2	0.5226	0.5472	0.2841	0.1506
C3	1.0669	0.9302	0.8739	0.7013
r-square	0.474	0.672	0.856	0.839

Figure 7-6 shows the relationship between the simulated runoff forecast (through September) and the cumulative runoff and representative snowpack for each month February through May. The graphs in the far-right column compare the runoff estimate using regression equations based on the cumulative runoff and snowpack against SacWAM simulations of runoff through September.

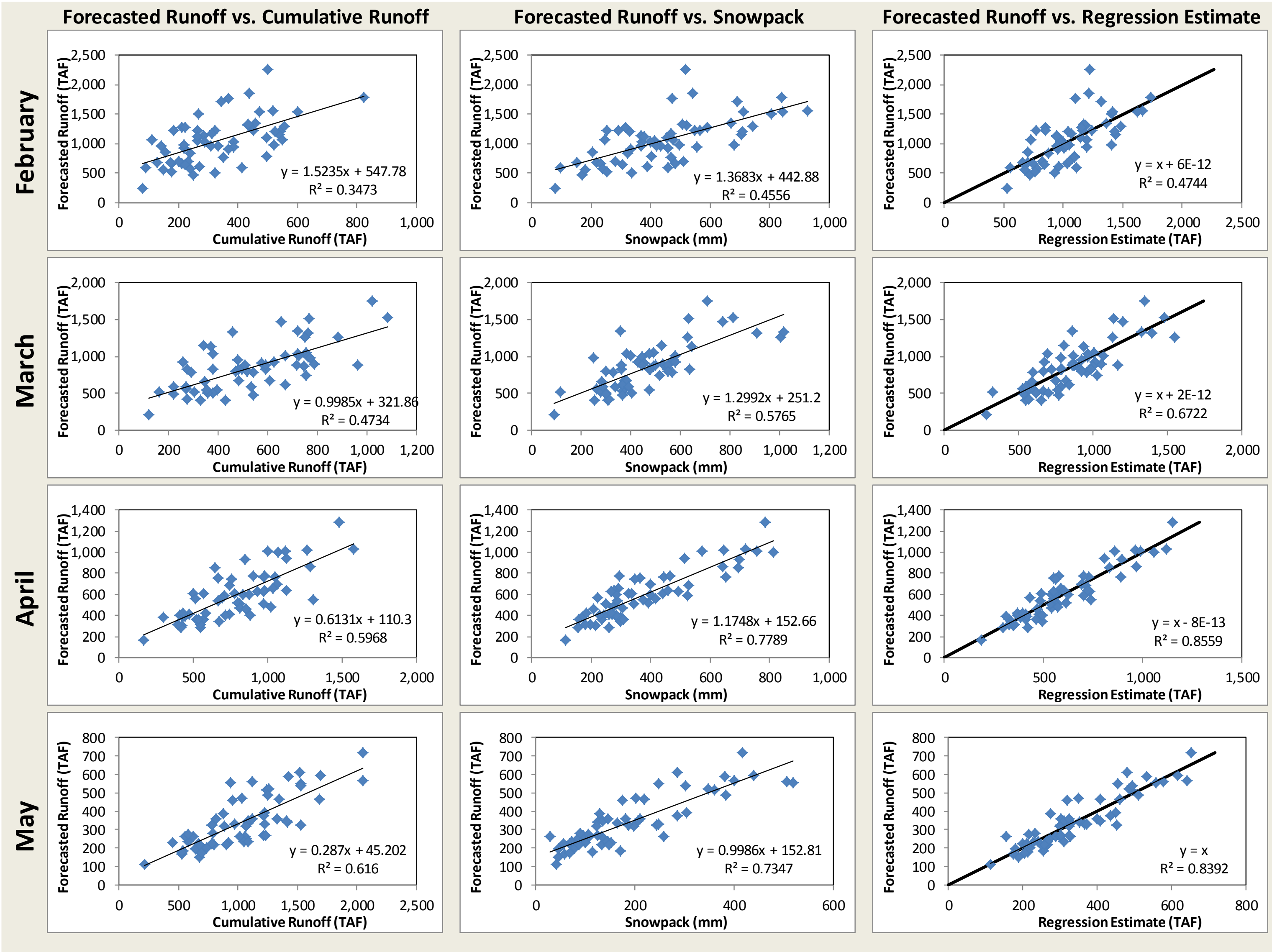


Figure 7-6. Development of Runoff Forecast Estimates Using Cumulative Runoff and Snowpack: Trinity River at Lewiston Dam

7.2.7.2 *SacWYT*

The Sacramento Valley index (*SRI 403030*) is determined using unimpaired runoff estimates from four locations: Sacramento River at Bend Bridge (*Sac Inflow Forecast*), Feather River inflow to Lake Oroville (*Fea Inflow Forecast*), Yuba River at Smartville (*Yub Inflow Forecast*), and American River inflow to Folsom Lake (*Amr Inflow Forecast*). The index also uses the previous year's value to take into consideration antecedent conditions within the basin. The index is sometimes referred to as the Sacramento Valley 40-30-30 index, because it considers 40 percent of the April-July Runoff Forecast, 30 percent of the October-March runoff, and 30 percent of the previous water year's index to calculate the current year's index. The Sacramento Valley index has five water-year classifications (Table 7-42).

Table 7-42. Sacramento Valley Water-Year Classifications

Water-Year Class	Annual Water Yield (TAF)	Code in WEAP
Wet	>= 9200	1
Above Normal	7800 to 9200	2
Below Normal	6500 to 7800	3
Dry	5400 to 6500	4
Critical	< 5400	5

Table 7-43 shows the regression coefficients that are used in estimating runoff forecasts for the Sacramento River at Bend Bridge. This relied on snowpack from four upstream catchments:

Table 7-43. Runoff Forecast Regression Coefficients for Sacramento River at Bend Bridge

Regression Coefficient	February	March	April	May
C1	1943.5467	848.0206	444.1380	541.3330
C2	0.5316	0.4581	0.2105	0.1161
C3	-3.6511	-0.4514	-1.7650	-1.3773
C4	3.1094	0.6741	4.6631	2.6186
C5	-3.5308	-3.1641	-9.1402	0.3465
C6	10.4702	10.1683	13.2429	-1.3175
r-square	0.407	0.608	0.826	0.807

Table 7-44 shows the regression coefficients that are used in estimating runoff forecasts for the Feather River at Lake Oroville. This relied on snowpack from one upstream catchment.

Table 7-44. Runoff Forecast Regression Coefficients for Feather River Inflows into Lake Oroville

Regression Coefficient	February	March	April	May
C1	1213.6026	582.0690	293.6549	291.8108
C2	0.6509	0.5578	0.2727	0.1179
C3	3.7878	2.3723	2.6826	2.3051
r-square	0.529	0.625	0.842	0.795

Table 7-45 shows the regression coefficients that are used in estimating runoff forecasts for the Yuba River at Smartville. This relied on snowpack from one upstream catchment.

Table 7-45. Runoff Forecast Regression Coefficients for Yuba River at Smartville

Regression Coefficient	February	March	April	May
C1	866.7323	461.1509	167.2367	141.6308
C2	0.4149	0.4195	0.1995	0.0793
C3	1.4127	1.0042	1.2248	1.1898
r-square	0.496	0.559	0.766	0.806

Table 7-46 shows the regression coefficients that are used in estimating runoff forecasts for the American River at Folsom Lake. This relied on snowpack from one upstream catchment.

Table 7-46. Runoff Forecast Regression Coefficients for American River Inflows into Folsom Reservoir

Regression Coefficient	February	March	April	May
C1	656.1048	151.9844	-276.4494	-74.1189
C2	-0.1730	0.2013	-0.1303	-0.0424
C3	2.8117	1.8706	2.2392	1.5050
r-square	0.537	0.636	0.872	0.920

Figure 7-7, Figure 7-8, Figure 7-9, and Figure 7-10 show the relationship between the simulated runoff forecast (through July) and the cumulative runoff and representative snowpack for each month February through May. The graphs in the far-right columns compare the runoff estimates using regression equations based on the cumulative runoff and snowpack against SacWAM simulations of runoff through July.

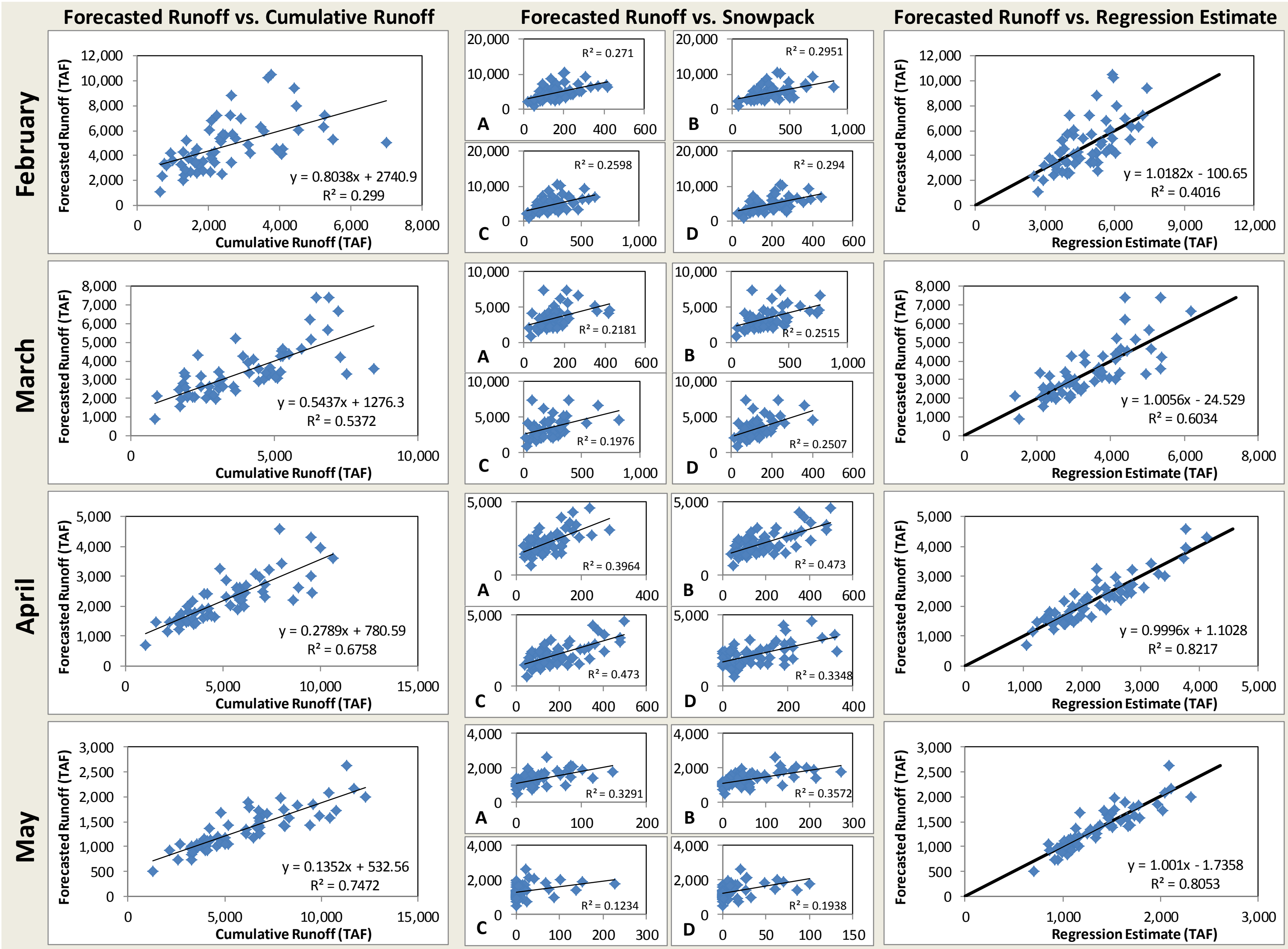


Figure 7-7. Development of Runoff Forecast Estimates Using Cumulative Runoff and Snowpack: Sacramento River at Bend Bridge

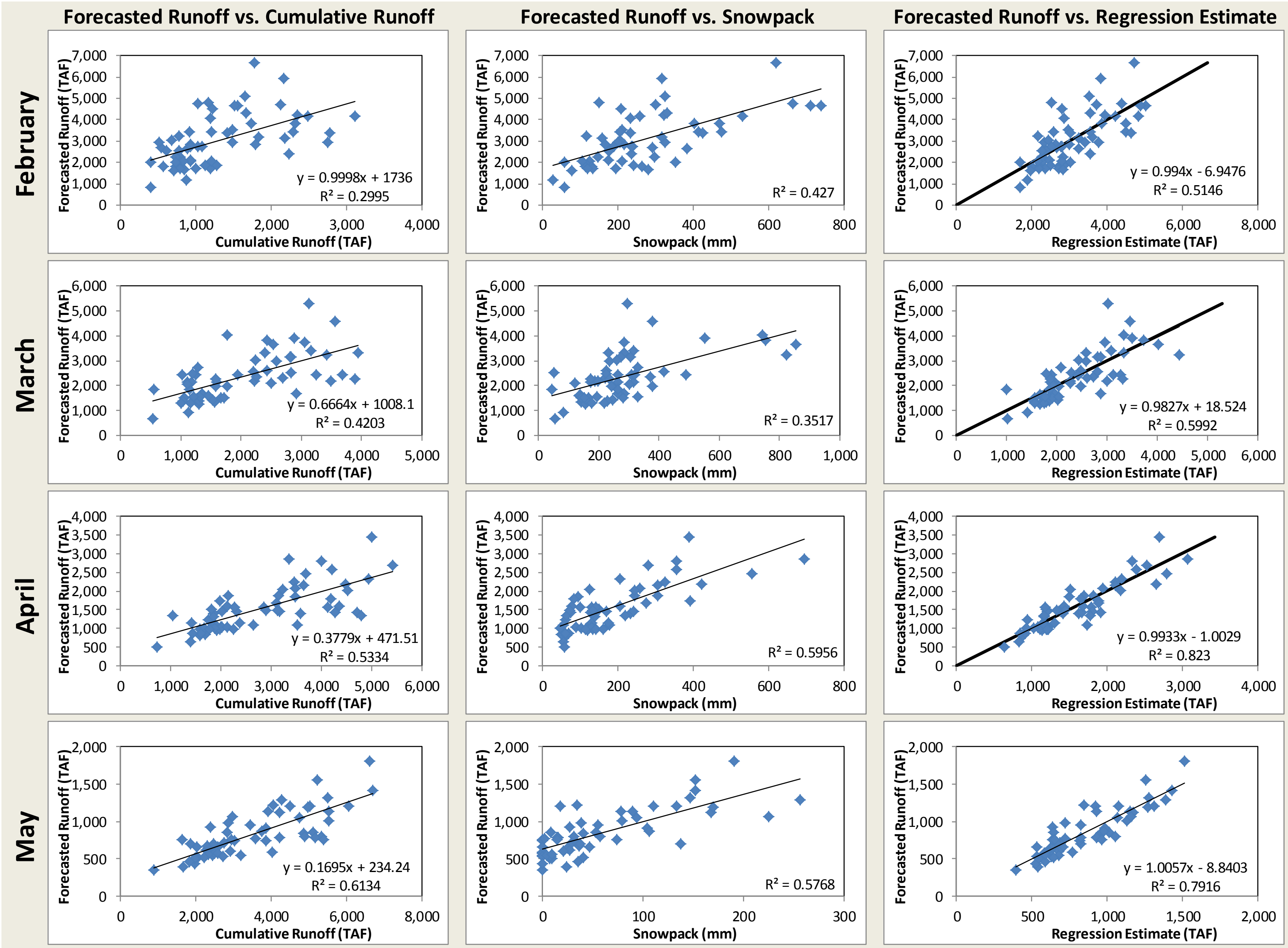


Figure 7-8. Development of Runoff Forecast Estimates Using Cumulative Runoff and Snowpack: Feather River at Lake Oroville

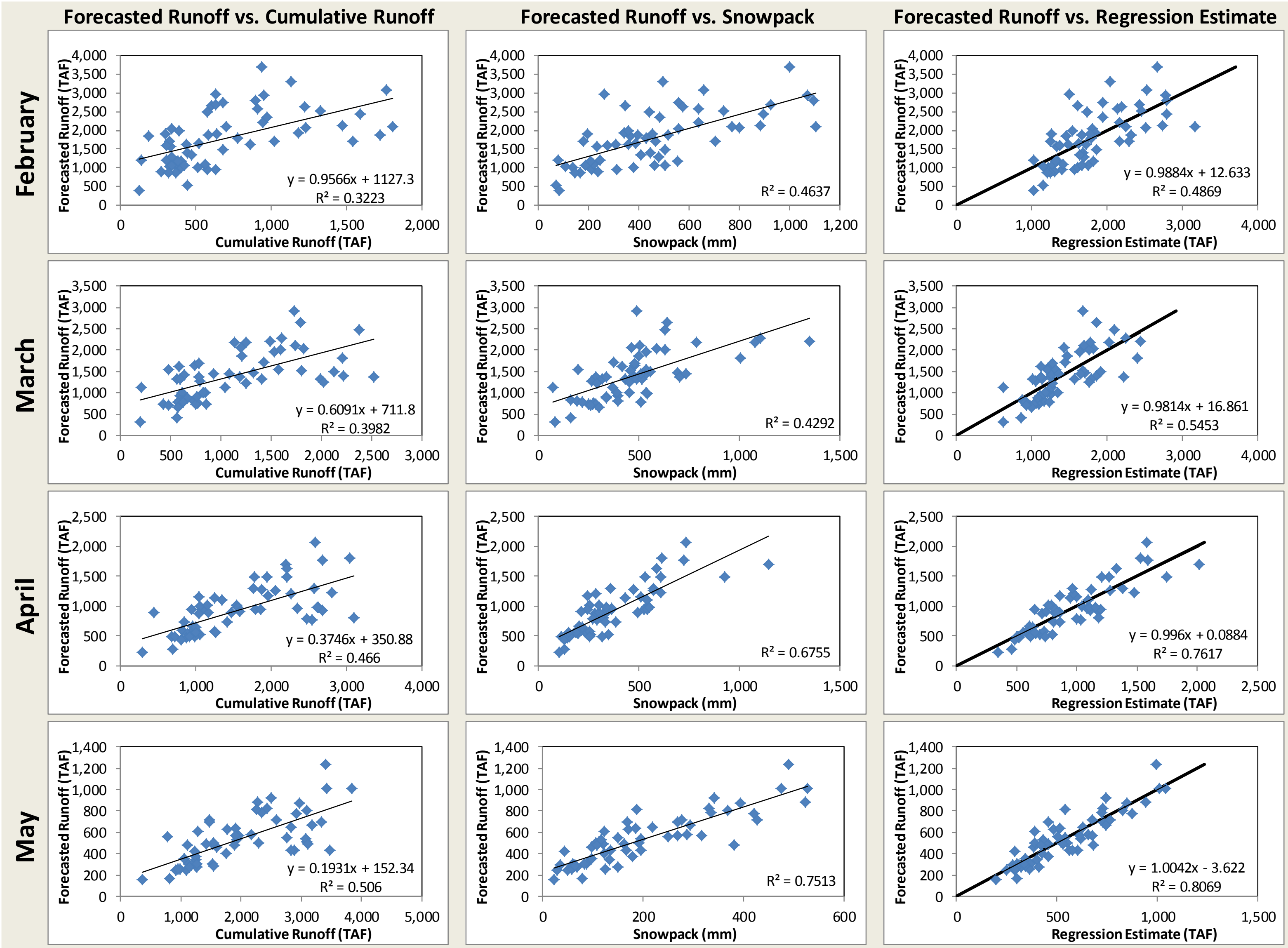


Figure 7-9. Development of Runoff Forecast Estimates Using Cumulative Runoff and Snowpack: Yuba River at Smartville

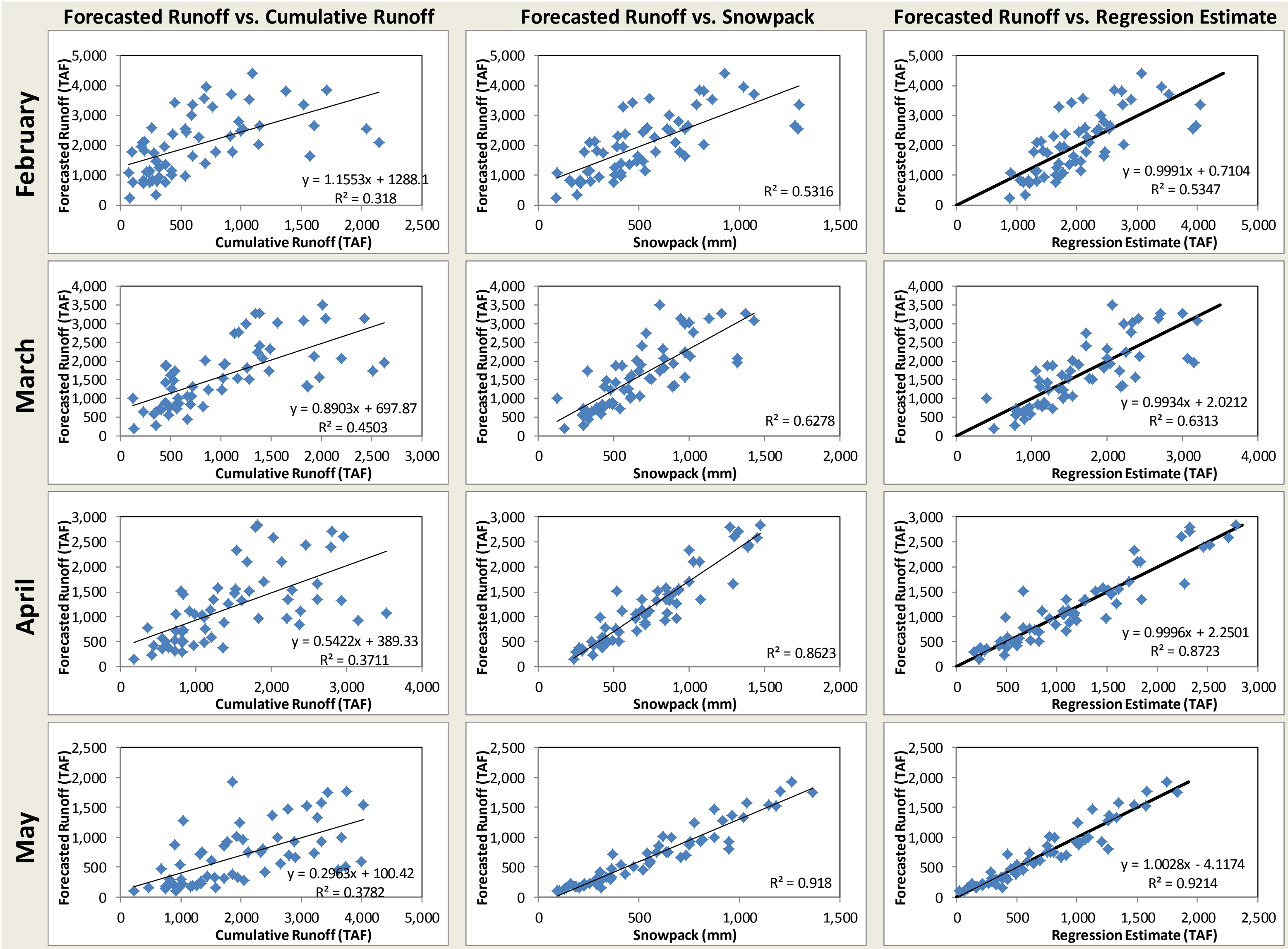


Figure 7-10. Development of Runoff Forecast Estimates Using Cumulative Runoff and Snowpack: American River at Folsom Lake

Figure 7-11 and Figure 7-12 show a comparison of the SacWAM estimate of the Sacramento 40-30-30 Water-Year Index to historical values over the period 1950-2009. The model generally agrees well the observed. It tracks the inter-annual variation well. However, it is slightly drier (less 4.76%) on average than the historical.

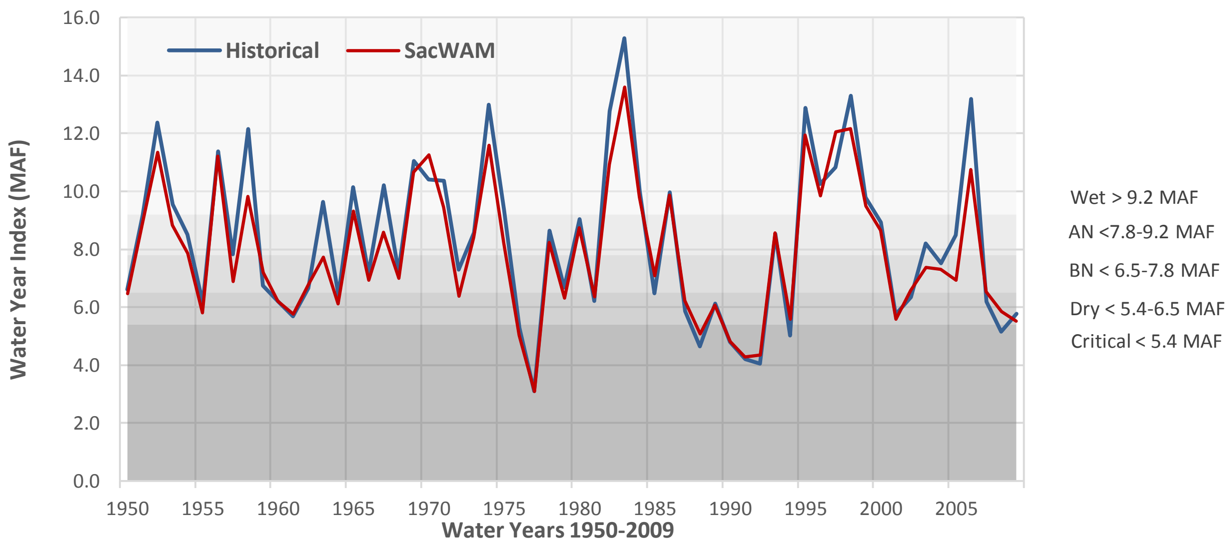


Figure 7-11. Comparison of SacWAM Forecast and Historical Sacramento Valley Water-Year Index

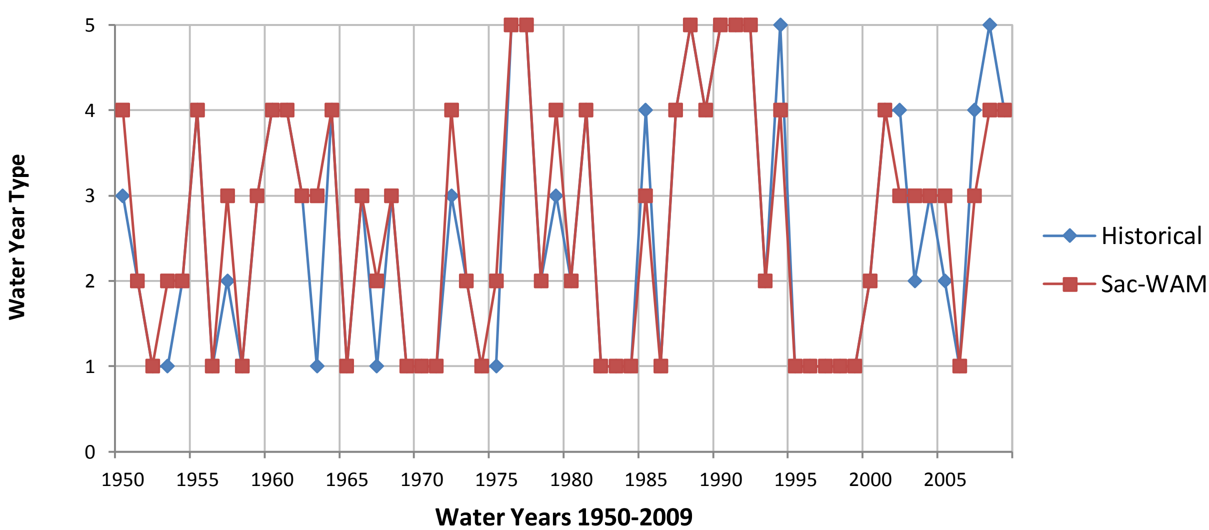


Figure 7-12. Comparison of SacWAM Forecast and Historical Sacramento Valley Water-Year Type

Wet=1; Above Normal=2; Below Normal=3; Dry=4; Critical=5

7.2.7.3 *Shasta*

Shasta reservoir has its own index, which is used to reduce water allocations to CVP Settlement and Exchange contractors when the index drops below a critical threshold. If the total full natural inflow (*Index*) into Shasta is less than 3.2 MAF in any given year, then it is declared a "Shasta critical" year. Also, if the total inflow in two consecutive years is less than 7.2 MAF, then the second year is determined to be a Shasta critical year.

The index is calculated as the sum of the flows to river in all the catchments above Shasta (*CumInflow*) and the *Runoff Forecast*, which is estimated using a regression equation based on runoff, upstream inflow, and snowpack in one of the watershed's high-altitude catchments.

Using this approach, SacWAM estimates that there were four Shasta critical years that occurred during the 1950-2005 historical period: 1976, 1977, 1991, and 1992. This compares well to the observed record, in which there were Shasta critical years in 1977, 1991, 1992, and 1994. The fact that the model did not accurately characterize the water years in 1976 or 1994 is a reflection of our modeling approach that does not rely upon perfect foresight. It should also be noted that the WEAP-estimated cumulative inflows in both of these years were close to the 3.2 MAF threshold—i.e. 3.02 MAF in 1976 and 3.77 MAF in 1994.

Table 7-47 shows the regression coefficients that are used in estimating runoff forecasts for the Sacramento River at Lake Shasta. This relied on snowpack from one upstream catchment.

Table 7-47. Runoff Forecast Regression Coefficients for Sacramento River Inflows into Lake Shasta

Regression Coefficient	February	March	April	May
C1	1790.9826	777.0032	462.7882	429.6317
C2	0.6847	0.5239	0.2754	0.1409
C3	7.1599	5.0095	6.2453	3.6454
r-square	0.345	0.577	0.737	0.786

Figure 7-13 shows the relationship between the simulated runoff forecast (through September) and the cumulative runoff and representative snowpack for each month February through May. The graphs in the far-right column compare the runoff estimate using regression equations based on the cumulative runoff and snowpack against SacWAM simulations of runoff through September.

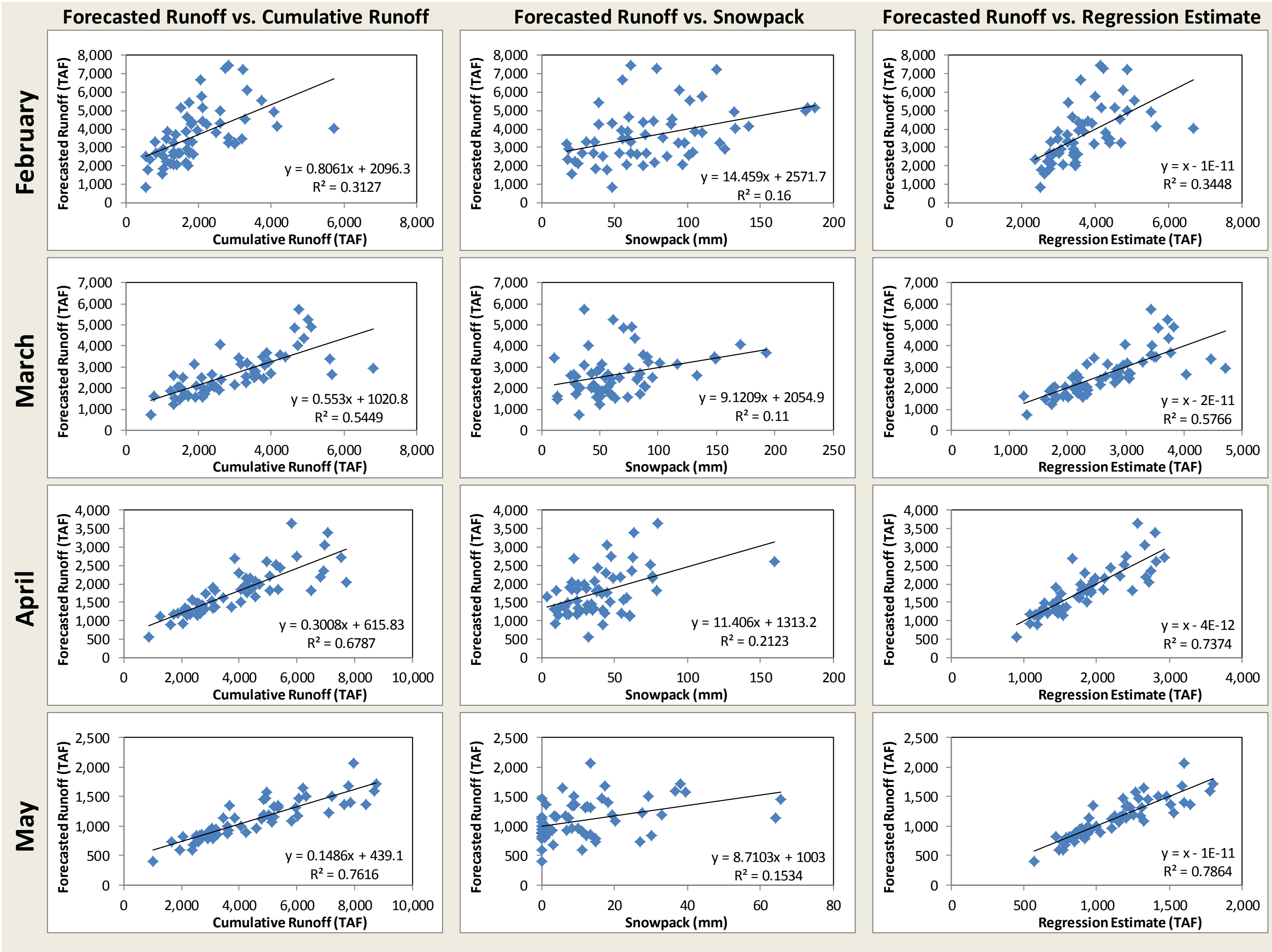


Figure 7-13. Development of Runoff Forecast Estimates Using Cumulative Runoff and Snowpack: Sacramento River at Lake Shasta

7.2.7.4 North Yuba

The North Yuba Index is a measure of the amount of water available in the North Yuba River at New Bullards Bar Reservoir. The index considers total inflow into New Bullards Bar for the current water year (including runoff forecasts) and carryover storage in New Bullards Bar from the previous water year minus the Federal Energy Regulatory Commission (FERC) Project License minimum pool amount of 234 TAF. The index is used to determine different flow schedules for the Yuba River at Smartville and Marysville. Thresholds for these flow schedules are summarized in Table 7-48.

Table 7-48. Flow Schedule Thresholds for the Yuba River

Flow-Schedule Year Type	North Yuba Index (TAF)
Schedule 1	>= 1400
Schedule 2	1040 to 1400
Schedule 3	920 to 1040
Schedule 4	820 to 920
Schedule 5	693 to 820
Schedule 6	<= 693

Table 7-49 shows the regression coefficients that are used in estimating runoff forecasts for the Yuba River at Smartville. This relied on snowpack from one upstream catchment.

Table 7-49. Runoff Forecast Regression Coefficients for the Yuba River at Smartville

Regression Coefficient	February	March	April	May
C1	928.7676	514.2141	209.3818	184.6664
C2	0.4348	0.4434	0.2179	0.0943
C3	1.4456	1.0289	1.2780	1.2827
r-square	0.494	0.557	0.765	0.810

Figure 7-14 shows the relationship between the simulated runoff forecast (through September) and the cumulative runoff and representative snowpack for each month February through May. The graphs in the far-right column compare the runoff estimate using regression equations based on the cumulative runoff and snowpack against SacWAM simulations of runoff through September.

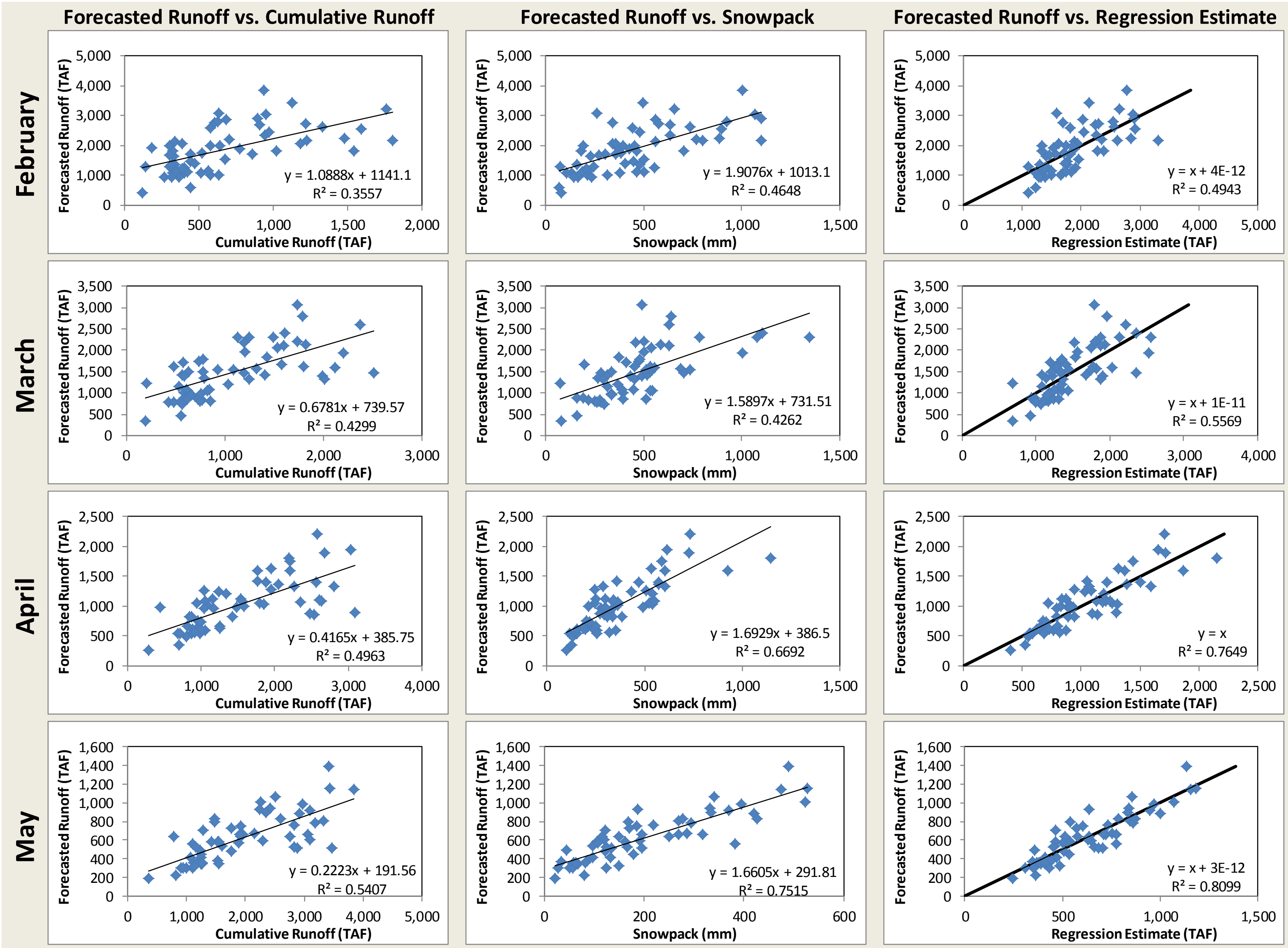


Figure 7-14. Development of Runoff Forecast Estimates Using Cumulative Runoff and Snowpack: Yuba River at Smartville

7.2.7.5 Mokelumne

Water-year classifications in the Mokelumne system are based on annual water yield.

JSA_AprSep_WYType

The JSA involving EBMUD, USFWS, and California Department of Fish and Wildlife (CDFW)…(Table 7-50). The flows

Table 7-50. Mokelumne River JSA April-to-September Water-Year Classifications

Water-Year Class	Annual Water Yield (TAF)	Code in WEAP
Normal/Above Normal	>= 890	1
Below Normal	500 to 889	2
Dry	300 to 499	3
Critical	<=299	4

Runoff Forecast

Table 7-51 shows the regression coefficients that are used in estimating runoff forecasts for the Mokelumne River at Pardee Lake. The total forecasted runoff is equal to *C1* + *C2* * *CumulativeInflowtoDate* + *C3* * *Snowpack* where *CumulativeInflowtoDate* consists of the Flow to River in the six upstream catchments, and *Snowpack* is the snowpack in the one catchment above 2000 m elevation.

Table 7-51. Runoff Forecast Regression Coefficients for the Mokelumne River at Pardee Lake

Regression Coefficient	February	March	April	May
C1	202.9001	73.4181	-47.1397	15.9103
C2	0.0008	0.2998	0.1105	0.1577
C3	0.8238	0.6548	0.6150	0.4153
r-square	0.610	0.680	0.873	0.914

Figure 7-15 shows the relationship between the simulated runoff forecast (through September) and the cumulative runoff and representative snowpack for each month February through May. The graphs in the far-right column compare the runoff estimate using regression equations based on the cumulative runoff and snowpack against SacWAM simulations of runoff through September.

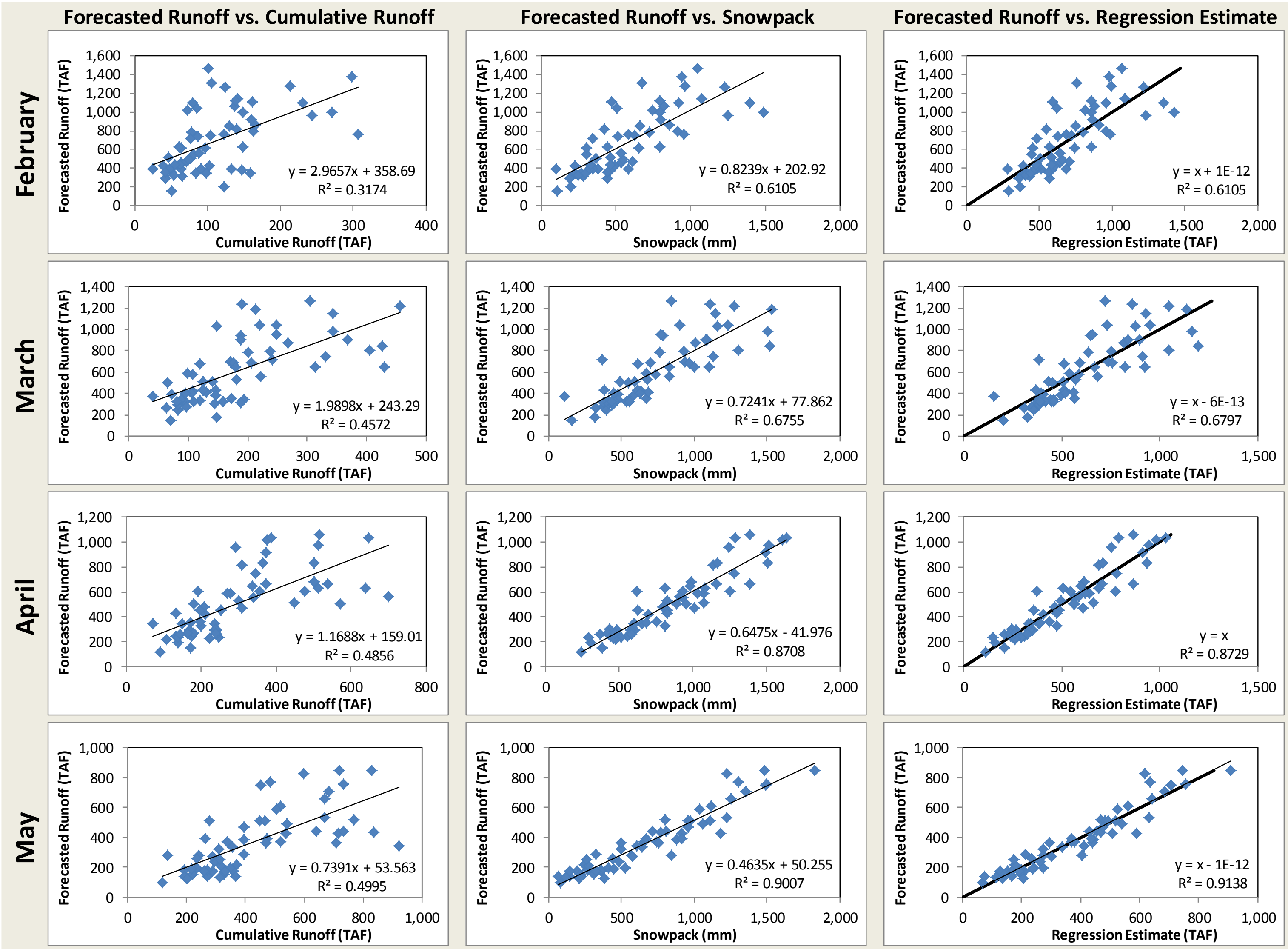


Figure 7-15. Development of Runoff Forecast Estimates Using Cumulative Runoff and Snowpack: Mokelumne River at Pardee

NorthFork_WYType

WYTs for the North Fork Mokelumne are revised based on Bulletin 120 forecasts. First determination of WYT is made in February. Final determination is made in May. WYT for the current account year is based on the average annual unimpaired flow (*AnnualUnimpairedFlowMokelumneHill*).

Table 7-52. North Fork Mokelumne River Water-Year Classifications

Water-Year Class	Annual Water Yield (TAF)	Code in WEAP
Wet	>= 958.7	1
Normal/Above Normal	724.4 to 958.7	2
Below Normal	518.1 to 724.4	3
Dry	376.1 to 518.1	4
Critical	<=376.1	5

7.2.7.6 Eight Rivers

The eight rivers index is the sum of the unimpaired Sacramento River flow at Bend Bridge, Feather River inflow to Lake Oroville, Yuba River flow at Smartville, American River inflow to Folsom Lake, Stanislaus River inflow to New Melones Lake, Tuolumne River inflow to New Don Pedro Reservoir, Merced River inflow to Lake McClure, and San Joaquin River inflow to Millerton Lake. It is used from December through May to set flow objectives as implemented in D-1641.

Note: When SacWAM references the eight rivers index, it reads the runoff for the current month. Thus, these runoff values need to be pre-processed for each climate scenario that SacWAM considers.

7.2.7.7 Folsom Hydro Forecast

These are hydrologic forecasts used in setting FMS requirements on the American River. There are forecasts of diversions for the various periods from March to September (specifically, end-of-month values *EoSep Diversion Forecast* and *EoMay Diversion Forecast*), which are based on the maximum of demands, water rights, and CVP allocation/contract amounts for each diversion in the basin. There are also forecasts of runoff for similar periods (*EoMay Runoff Forecast, EoSep Runoff Forecast*), based on estimates of inflows into Folsom.

7.2.7.8 James Bypass

A timeseries of monthly flows from the James Bypass into the Mendota Pool. It is used to estimate the water supply index (WSI) for CVP South of Delta allocations.

7.2.7.9 American

UIMarNov

UIMarNov represents the unimpaired inflow to Lake Folsom from March through November of the current water year. It is calculated using *UInflow* that is described below.

UInflow

UInflow represents the monthly unimpaired inflow to Lake Folsom and is read from timeseries data.

7.2.7.10 *ShastaStorage*

Previous month's storage in Shasta Lake. This variable is referenced by routines used to set Sacramento River in-stream flow requirements below Keswick (see Section 7.2.3.3), to set the rule curve for CVP portion of San Luis storage (see Section 7.2.1), and to balance storage with Trinity (see Section 7.2.16).

7.2.7.11 *FolsomStorage*

Previous month's storage in Folsom Lake. This variable is referenced by routines used to set the rule curve for the CVP portion of San Luis storage (see Section 7.2.1) and to set the American River FMS (see Section 7.2.3.7).

7.2.7.12 *SRI Forecast*

The SRI forecast is a timeseries of forecasts of SRI for January and February. This forecast is used in setting FMS requirements on the American River in those months (Section 7.2.7.9). The timeseries is the same as that used in the CalSim II model.

7.2.7.13 *San Joaquin*

7.2.8 CVP Allocations

SacWAM uses the same basic approach as CalSim II (2013 SWP Reliability Report: DWR, 2014e) to set contract allocation levels to CVP and SWP contractors in the Sacramento Valley. For calibration purposes, SacWAM also includes switches that allow the user to fix CVP allocations north and/or south of the Delta to those simulated by CalSim II (in the 2013 SWP Reliability Report). These switches are located in *Other\Calibration Switches\Simulate NOD CVP Allocation* and *Other\Calibration Switches\Simulate SOD CVP Allocation* (Sections 7.1.2 and 7.1.3).

The procedure for setting the annual allocation to CVP contractors is found in WEAP's data tree structure under *Other Assumptions\Ops\CVP Allocations*. The allocation that is the end result of this procedure is referenced from each of the transmission links that divert surface water to CVP contractors. This allocation is applied to a monthly distribution of contract amounts to set an upper limit on diversions. These monthly values are based on Exhibit A of each contract, which specifies the distribution of the contractors' base supply and project water[17] over the irrigation season, April-October.

Figure 7-16 compares the estimated CVP allocations resulting from this procedure to both historic and simulated values from CalSim II over the period 1990-2009.

[17] Base supply is the quantity of water that Reclamation agrees may be diverted, without charge, each month from April through October. Project water refers to additional quantities of water that may be diverted from April to October, but are subject to pricing and other federal requirements.

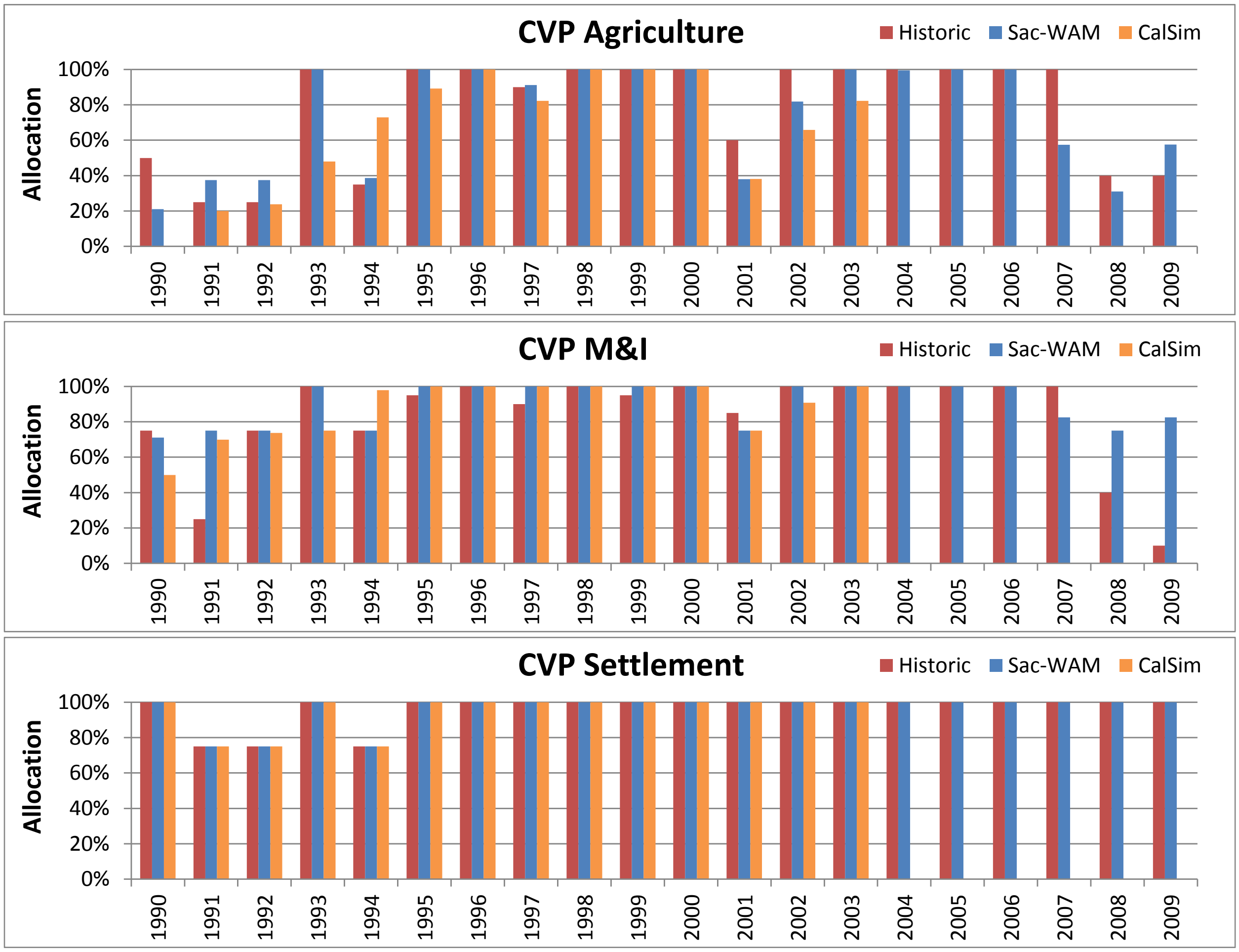


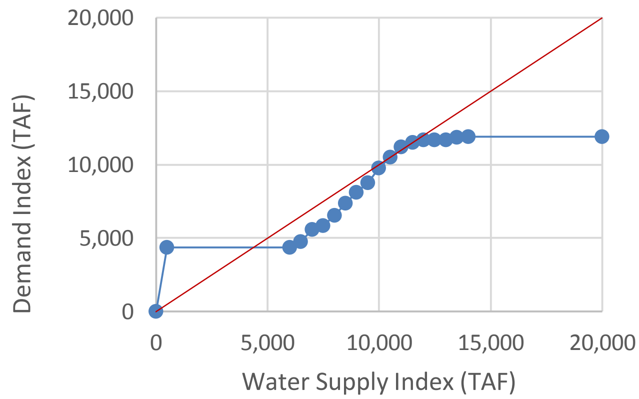
Figure 7-16. Comparison of SacWAM, Historical, and CalSim II CVP Allocations (1990-2009)

This approach for allocating water to CVP relies on using a series of curves to manage uncertainty in promising water to contractors. These curves are generally used as a way of mitigating the risk of promising water given an assessment of water supplies for the water year. That is, they are conditioned such that within the model the full allocations that are promised during the allocation period (Feb-May) are almost always satisfied.

The process occurs in the late winter and early spring as the water supply outlook is becoming clearer. It begins by estimating the available water supplies by summing the existing water in storage and the forecasted inflows—WSI. SacWAM then estimates the level of demand that can be met with this supply (i.e. the *DemandIndex*, or DI) using a WSI-DI curve. This is shown in Table 7-53 and the accompanying graph.

Table 7-53. CVP Water Supply Index – Demand Index Curve

Water Supply Index (TAF)	Demand Index (TAF)
0	0
500	4,381
6,000	4,381
6,500	4,779
7,000	5,607
7,500	5,855
8,000	6,553
8,500	7,375
9,000	8,093
9,500	8,765
10,000	9,755
10,500	10,509
11,000	11,194
11,500	11,490
12,000	11,677
12,500	11,698
13,000	11,698
13,500	11,879
14,000	11,904
20,000	11,904

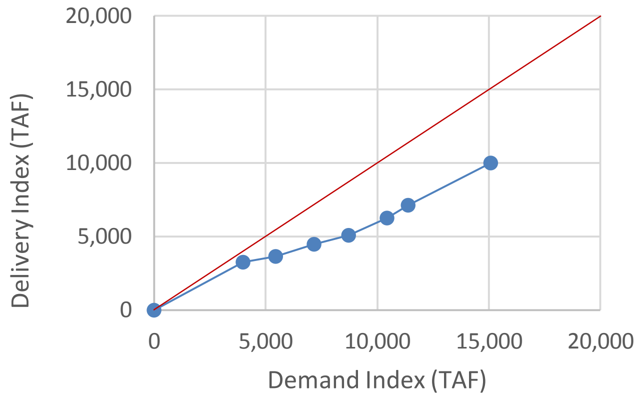


As the curve shows, under particularly low water supply conditions, DI is flat, which indicates that there exists some level of hard water demands that exist even in the driest conditions. DI is also flat at high levels of water supply because the system demand is not unlimited and above a certain water supply threshold all water demand can be satisfied. Under intermediate water supply conditions, an increase in water supply translates into an increase in the water demand that can be satisfied. However, the curve often falls below the 1:1 line, suggesting that a smaller percentage of the available supply is made available to meet demand. This is in itself an acknowledgement that water released from storage may not always reach demands due to regulatory and/or physical constraints, so the model is conditioned to reduce the risk of this occurring by promising to deliver less water.

DI is the sum of both delivery and carryover storage demands. Thus, once the DI has been established, the model then references another lookup table to determine how this water should be partitioned between water left in storage (i.e. carryover) and water delivered. This is shown in Table 7-54 and the paired graph.

Table 7-54. CVP Demand Index — Delivery Index

Demand Index (TAF)	Delivery Index (TAF)
0	0
3,990	3,227
5,442	3,657
7,162	4,476
8,717	5,079
10,434	6,245
11,395	7,110
15,100	9,999



Note that as DI decreases, a smaller percentage of the available supply is committed to carryover storage relative to the amount that is delivered to meet current water demands. This is the second component of risk management in the allocation process.

Once this delivery target has been established using the Delivery-Carryover curve, this total volume of water is evaluated relative to the total annual project demands. If the delivery target is less than the sum of these demands, then a series of cuts is applied to different water users to determine the allocations as a percentage of contracts. The sequence of these cuts is outlined in the following flowchart, Figure 7-17 (where all values are expressed as volumes of water).

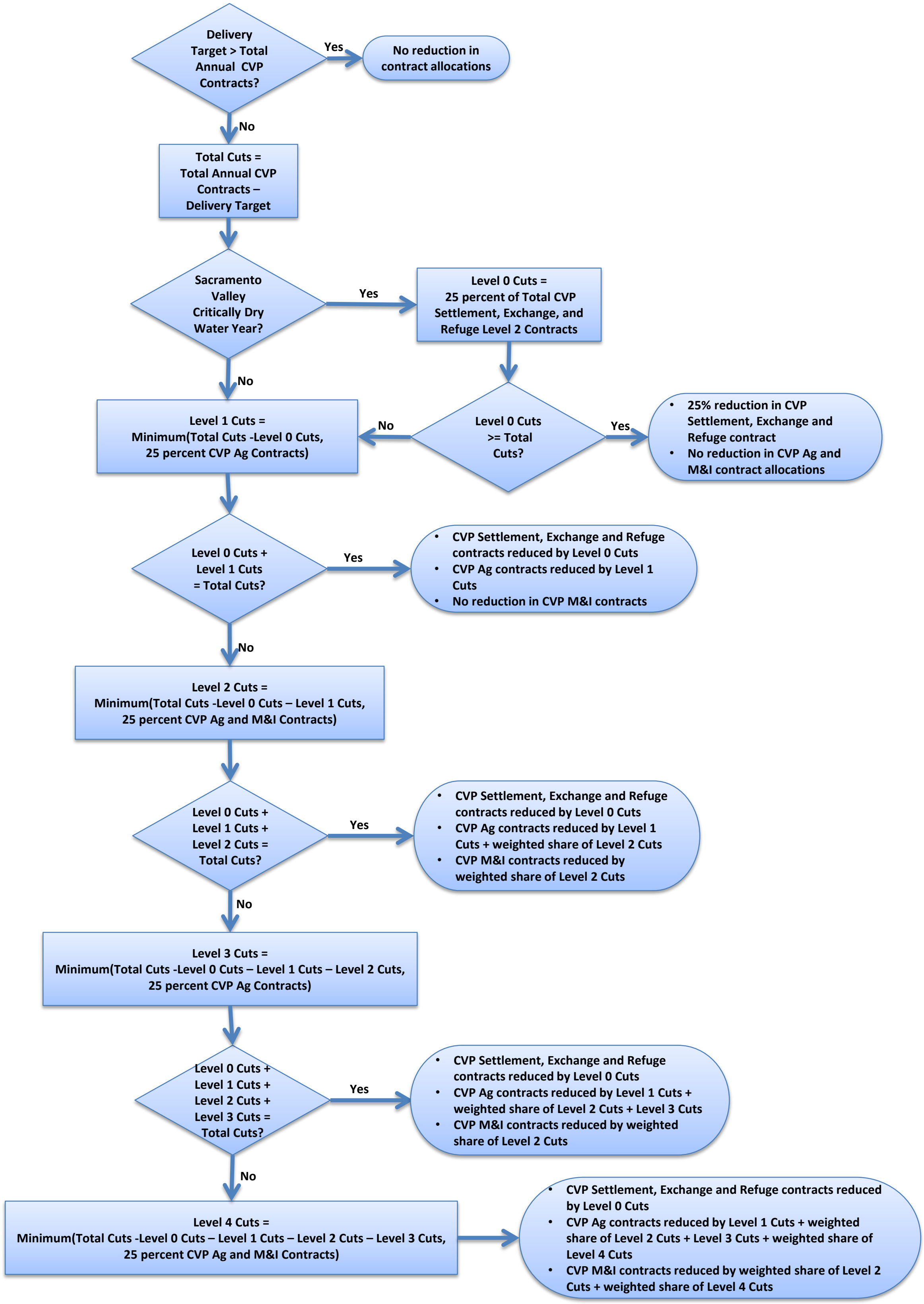


Figure 7-17. Central Valley Project Contract Allocation Logic

Sacramento Valley Settlement contractors and San Joaquin Valley Exchange contractors possess water rights that were secured before the construction of CVP, which by prior appropriation assures them a higher level of reliability for their supplies. According to their agreement with Reclamation, Settlement and Exchange contractors receive 100 percent of their contract amounts in all years except "critically dry" water years, as defined by the Shasta Hydrological Index. In Shasta critical years (i.e. when the total inflow to Shasta Reservoir is below 3.2 MAF), Settlement and Exchange contractors receive 75 percent of their contract amounts.

When making the yearly allocations for Settlement and Exchange contractors, the WEAP model must account for the cumulative inflows into Shasta in order to designate the Shasta Hydrological Index. In an effort to approximate the allocation process as it happens in reality, WEAP does not use perfect foresight to estimate inflows to Shasta for the remainder of the water year after allocations are set (i.e. April-September). Instead the model relies on a heuristic to estimate this quantity of water. This heuristic is explained in greater detail in Section 7.2.7.3.

7.2.8.1 *Contracts_XX*

These parameters contain the total contract values for their respective contracts. Table 7-55 shows abbreviations used in these parameter names.

Table 7-55 Abbreviations Used in Contract Parameters

Abbreviation	Water Service Contractor Type
AG	agriculture
EX	exchange
MI	municipal and industrial
north	north of Delta
RF	refuge
SC	settlement
south	south of Delta

7.2.8.2 *System*

The *System* branch contains the parameters described in the previous sections that are used to set the WSI, DI, Delivery Index, and to make subsequent adjustments to CVP water allocations in the Sacramento Valley (aka NOD CVP Allocations). Table 7-56 presents these parameters in their entirety. These include the corresponding CalSim II allocations that may be applied during model calibration (*Alloc_AG_CalSim, Alloc_MI_CalSim,* and *Alloc_SC_*CalSim) such that demand levels are fixed within SacWAM. The parameters also include total contract amounts (*Contracts_Total*) as well as expressions for WSI, DI (*DemandIndex*), and the Delivery Index. Final allocation levels for each demand category—agriculture (*Percent_Alloc_AG*), refuge (*Percent_Alloc_RF*), settlement (*Percent_Alloc_SC*), exchange (*Percent_Alloc_EX*), and M&I contractors (*Percent_Alloc_MI*)—are each located under this branch as well.

Table 7-56 CVP Allocations\System Sub-Branches

System\	Description
Alloc_AG_CalSim	Timeseries (1922-2003) of CalSim II allocation values for CVP NOD Agricultural Services contractors
Alloc_MI_CalSim	Timeseries (1922-2003) of CalSim II allocation values for CVP NOD Urban contractors
Alloc_SC_CalSim	Timeseries (1922-2003) of CalSim II allocation values for CVP NOD Settlement contractors
Contracts_Total	Total CVP contract amounts (TAF) north and south of the Delta
Cuts	*See following paragraph.*
DeliveryIndex	The lesser of *Contracts_Total* and *DeliveryIndex_first*
DeliveryIndex_first	The amount of DemandIndex that can be used for delivery
DemandIndex	The amount of the current water supply that can be allocated to delivery and carryover storage
DivReq	Diversion requirement
Percent_Alloc_AG	Final percentage allocation for CVP NOD Agricultural Services contractors
Percent_Alloc_EX	Final percentage allocation for CVP Exchange contractors
Percent_Alloc_MI	Final percentage allocation for CVP NOD Urban contractors
Percent_Alloc_RF	Final percentage allocation for CVP NOD Refuge contractors
Percent_Alloc_SC	Final percentage allocation for CVP Settlement contractors
WaterSupplyEst	Estimated water supply for the current water year

The *Cuts* sub-branch contains all of the parameters involved in applying the logic outlined in Figure 7-17. "Cuts" in this sense refers to the volume of water that is associated with allocation reductions for particular demand categories. There are five possible levels of cuts, beginning with cuts to settlement, refuge and exchange contractors in Shasta Critical years (level 0) and progressing through to final reductions for agriculture and M&I contractors (level 4). At each level, the maximum possible allocation reduction is 25 percent of contract demands. Thus, agriculture, which is involved in each step 1 through 4 may be reduced to zero percent allocation by the end of the cuts procedure. Whereas, M&I may only be reduced to 50 percent of their contract demand, because they are implicated in only level 2 and level 4 cuts. At each level, a percentage less than 25 percent may be selected if it is sufficient to meet the remaining deficit between contract demands and the target delivery volume (or delivery index).

7.2.8.3 *South*

This sub-branch contains parameters similar to those described in the previous section to set allocation levels for different categories of CVP contractors. These parameters focus on setting allocations for CVP contractors south of the Delta. In this case, however, SacWAM does not use the same set of WSI-DI curves to estimate available water supplies. Instead, it uses a Delta Index to estimate water supply conditions and an Export Index to estimate how much of that water supply may be diverted south of the Delta.

The Delta Index is set by evaluating the cumulative water year inflows (i.e. inflows since the previous October) plus the forecasted inflows for the remainder of the water year (i.e. through September) for the Sacramento River at Bend Bridge, Feather River at Oroville, Yuba River at Smartville, and American River at Folsom. The Export Index is set using a lookup table that relates the Delta Index to a volume of water that may be pumped from the Delta. The SOD Delivery Index is then determined by making adjustments to the Export Index based on the amount of water that the CVP has stored in San Luis reservoir.

Final allocation levels are calculated by first determining a demand deficit, which is equal to the difference between South of Delta contract demands and the Delivery Index, and then proceeding through a series of cuts (similar to those implemented for the Sacramento Valley) that systematically reduce the volume of water available to the different demand categories until the total volume of cuts is equal to the demand deficit.

7.2.8.4 *CVP_SC*

CVP_SC represents the final percentage allocation for CVP settlement contractors. It is this parameter that is referenced throughout the model to constrain surface water diversions through transmission lines from the Sacramento River.

7.2.8.5 *CVP_Ag*

CVP_Ag represents the final percentage allocation for CVP agricultural contractors in the Sacramento Valley. It is this parameter that is referenced throughout the model to constrain surface water diversions through transmission lines to agricultural services contractors.

7.2.8.6 *CVP_Urb*

CVP_Urb represents the final percentage allocation for CVP M&I contractors in the Sacramento Valley. It is this parameter that is referenced throughout the model to constrain surface water diversions through transmission lines to M&I contractors.

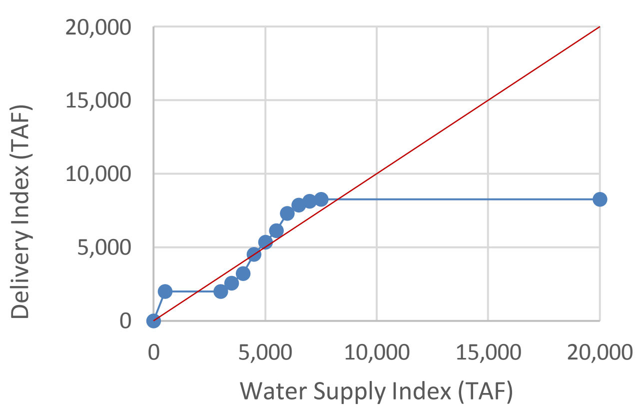
7.2.9 SWP Allocations

SacWAM uses the same basic approach as CalSim II (SWP Reliability Report: DWR, 2014e) to set contract allocation levels to CVP and SWP contractors in the Sacramento Valley.

The procedure for calculating SWP contract allocations has some similarities to the one used to calculate CVP allocations. This procedure also starts by assessing the available water supply, which for SWP is the sum of its available storage from the previous month in San Luis and Oroville plus the forecasted runoff (through September) of the Feather River into Oroville. DI is again calculated from WSI, with values shown in Table 7-57 (where a linear interpolation is used between points on this curve).

Table 7-57 SWP Water Supply Index – Demand Index Curve

Water Supply Index (TAF)	Demand Index (TAF)
0	0
500	1,994
3,000	1,994
3,500	2,534
4,000	3,212
4,500	4,513
5,000	5,343
5,500	6,106
6,000	7,298
6,500	7,852
7,000	8,111
7,500	8,242
2,0000	8,242



Unlike the procedure for the CVP, this allocation routine does not use a separate curve to separate the delivery and carryover storage components of DI. Instead, the routine assumes that the target carryover storage for SWP in Lake Oroville is 1,000 TAF plus half of the volume of water above 1,000 TAF carried over from the previous water year (i.e. one half end-of-September storage above 1,000 TAF). The initial allocation also assumes that the target SWP carryover storage in San Luis is 110 TAF. Thus, we use the following equation to calculate and initial percentage allocation.

$$Initial\ Percent\ Allocation = Maximum\left\{0, \frac{Demand\ Index - 110\ TAF - 1000\ TAF}{SWP\ Table\ A + Maximum[0, \frac{1}{2}(Oroville\ Carryover\ Storage - 1000\ TAF)]}\right\}$$

where the numerator is the estimated total SWP delivery and the denominator is the adjusted total demand.

SacWAM then uses this allocation estimate to update the carryover target for SWP storage in San Luis using the following equation.

$$SWP\ San\ Luis\ Drainage\ Target = Minimum\left\{\begin{matrix} SWP\ San\ Luis\ Storage\ Capacity, \\ 110\ TAF + Maximum[0, SWP\ Table\ A * (Initial\ Percent\ Allocation - 1) - 250\ TAF] \end{matrix}\right\}$$

This updated SWP San Luis carryover target is then used to update the percentage allocation.

$$Adjusted\ Percent\ Allocation = Maximum\left\{0, \frac{Delivery\ Index - SWP\ San\ Luis\ Drainage\ Target - 1000\ TAF}{SWP\ Table\ A\ + Maximum[0, \frac{1}{2}\ (Oroville\ Carryover\ Storage - 1000\ TAF)]}\right\}$$

This equation forms the basis of the SWP Table A contract allocation. It is updated February through May as the estimate of water supply becomes clearer. It is also adjusted during the spring pulse period (April-May) when regulatory constraints limit the ability of SWP to move water through the Delta to the export pumps at Banks. The allocation of water during these two months assumes the bulk of water will be delivered from San Luis after some minimum level of SWP export. So, the April-May allocation is conditioned upon the available SWP water in San Luis (see Section 7.2.1).

The procedure for setting the annual allocation to SWP Table A contractors is found in WEAP's data tree structure under *Other Assumptions\Ops\SWP Allocations*. The allocation that is the end result of this procedure is referenced from each of the transmission links that divert surface water to SWP contractors. This allocation is applied to a monthly distribution of contract amounts to set an upper limit on diversions.

Figure 7-18 compares the estimated SWP allocations resulting from this procedure to both historic and simulated values from CalSim II over the period 1990-2009.

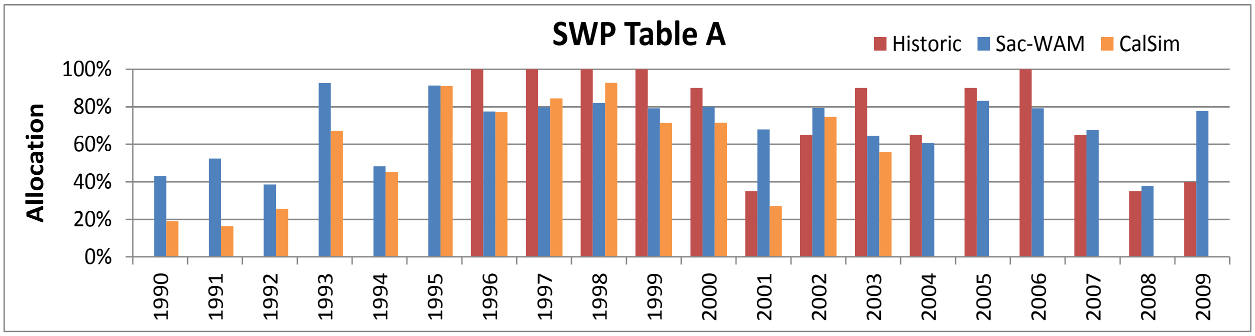
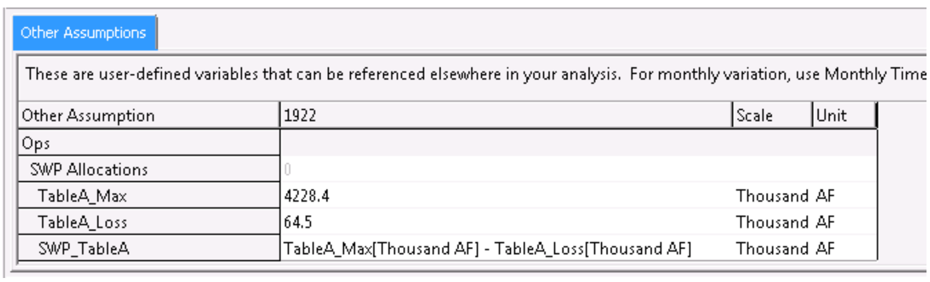


Figure 7-18. Comparison of SacWAM, Historic, and CalSim II SWP Allocations (1990-2009)

7.2.9.1 *TableA parameters*

SacWAM calculates a percentage of contract allocation for SWP Table A contract demands. It assumes that the total Table A contract demand is 4,228.4 TAF/year (*TableA_Max*) and that there is an annual delivery loss of 64.5 TAF (*TableA_Loss*). Thus, for calculation purposes, we use a value of 4,163.9 TAF for SWP Table A Contracts (*SWP_TableA*).


Other Assumptions

These are user-defined variables that can be referenced elsewhere in your analysis. For monthly variation, use Monthly Time

Other Assumption	1922	Scale	Unit
Ops			
SWP Allocations	0		
TableA_Max	4228.4	Thousand	AF
TableA_Loss	64.5	Thousand	AF
SWP_TableA	TableA_Max[Thousand AF] - TableA_Loss[Thousand AF]	Thousand	AF

7.2.9.2 *SOD parameters*

The South of Delta parameters describe what the model should do in case of a shortage (*SOD_TableAShortage*) and calculate cumulative SWP deliveries (*SOD_CumulativeDeliveries*), which is defined as the sum of South Bay Aqueduct (SBA)–, South Coast–, San Joaquin–, and Central Coast Tulare– cumulative deliveries (*SBA\CumulativeDeliveries*, *SouthCoast\CumulativeDeliveries*, *SJ\CumulativeDeliveries*, and *CCTL\CumulativeDeliveries*, respectively).

7.2.9.3 *Initial Allocation*

Initial Allocation parameters provide an initial estimate of the allocation to SWP Table A contractors for the current water year. This allocation estimate is represented in TAF with the variable *WSIDI_SWPdel.*

Brief descriptions of sub-branches under *InitialAllocation* are provided in Table 7-58.

Table 7-58. Other Assumptions\Ops\SWP Allocations\InitialAllocation Sub-Branches

InitialAllocation\	Description
co_correct	Timeseries (1922-2003) of CalSim II percent allocations for SWP Table A contractors (used for comparison or calibration only)
WaterSupplyEst	Estimated water supply for the current water year
DemandIndex	
DI_Buffer	Demand buffer
DrainTarget_Buffer	Buffer storage to add to end-of-September SWP storage
init_SWPRuleDrainTar	Initial end-of-September storage target
SWPRuleDrainTarget	See equation above for SWP San Luis Drainage Target
Allocation_init	See equation above for Initial Percent Allocation
Allocation_adjustment	See equation above for Adjusted Percent Allocation
WSIDI_SWPdel	Initial estimate of the volume of water available to State Water P contractors

Key: SWP=State Water Project.

7.2.9.4 *Export Capacity_Adjust*

The SWP allocation procedure also considers that the capacity to pump water from the Delta varies throughout the year and may be adjusted based on hydrologic conditions within the San Joaquin basin. Brief descriptions of sub-branches *Export Capacity_Adjust* are described in Table 7-59.

Table 7-59. Other Assumptions\Ops\SWP Allocations\ExportCapacity_Adjust Sub-Branches

ExportCapacity_Adjust\	Description
estSWPExp	Estimated capacity to export water from the Delta. Monthly values adjusted when San Joaquin Index is wet or flows at Vernalis exceed 16000 cfs
fact_SWP	SWP delivery factor
buff_SWP	SWP San Luis buffer storage
SWPDelCapEst	Estimated delivery capacity to SWP export zone. Equal to *estSWPExp* plus SWP storage in San Luis minus *buff_SWP*
deltar_expmax	Adjusted January-to-May delivery target for SWP export zone

Key: SWP=State Water Project.

7.2.9.5 *SL_Adjust*

The SWP allocation procedure considers that in some years there may be sufficient storage in San Luis to justify an increase in the allocation. This adjustment is made in the last two months of the allocation period (April and May). Brief descriptions of sub-branches *SL_Adjust* are presented in Table 7-60.

Table 7-60. Other Assumptions\Ops\SWP Allocations\SL_Adjust Sub-Branches

SL_Adjust\	Description
AprMay_Dry	Assessment of delivery capacity based on April-May storage in SWP San Luis
Allocation_1	Adjusted SWP allocation based on comparison of *AprMay_Dry* with *WSIDI_SWPExp* and *deltar_expmax*

Key: SWP=State Water Project.

7.2.9.6 *Final_Allocation*

These branches represent the calculations required to compute the final Table A allocations. Brief descriptions of sub-branches *Final_Allocation* are presented in Table 7-61.

Table 7-61. Other Assumptions\Ops\SWP Allocations\Final_Allocation Sub-Branches

Final_Allocation\	Description
TableA_Alloc	Timeseries (1922-2003) of CalSim II SWP Table A allocations (used for comparison/calibration only)
Allocation_2	Minimum of *Allocation_1* and *TableA_Max*
Allocation_Final	Fixes the allocation for the months outside the allocation period (July-January)
SWP_percent_delivery	Final allocation as a percentage of Table A demands
FSC_percent_delivery	Final allocation for SWP Feather River Settlement contractors. Reduced to 50 % only in critically dry years.

Key: SWP=State Water Project.

7.2.9.7 *SBA / SouthCoast / CCTL / SJ*

SWP water users in the export zone include contractors in the South Coast, the San Joaquin Valley (SJ), the Central Coast and Tulare basin (CCTL), as well as users taking water from SBA. SacWAM considers that in some months these users may not receive the entirety of their demand request. As such, the model includes a routine to augment demands in certain months based on delivery deficits that occur in previous months.

Table 7-62. Other Assumptions\Ops\SWP Allocations\SBA & SouthCoast & CCTL & SJ Sub-Branches

Sub-Branch	Description
TableA_XXX	Annual Table A contract amounts for SBA, SouthCoast, CCTL, or SJ
CumulativeDeliveries	Total deliveries to demand zone since January 1st
MonthlyDemandPattern	See Table 7-63
RemainingDemandPattern	See Table 7-64
MakeUpWater	The amount of water to add to the current month's demand based on delivery deficits in previous months

Table 7-63. Monthly Percentage of Annual Demand Under Different Table A Allocation Levels

	Percent Table A Allocation				
	0-30	**30-45**	**45-60**	**60-70**	**70-100**
October	11%	9%	11%	10%	9%
November	8%	9%	10%	9%	9%
December	10%	13%	9%	9%	9%
January	4%	4%	3%	5%	7%
February	4%	1%	3%	5%	6%
March	1%	2%	1%	5%	7%
April	1%	2%	5%	7%	8%
May	9%	8%	6%	7%	9%
June	13%	11%	10%	9%	8%
July	13%	14%	13%	11%	9%
August	14%	14%	15%	12%	10%
September	12%	13%	14%	11%	9%

Table 7-64. Percentage of Annual Demand Remaining Under Different Table A Allocation Levels

	Percent Table A Allocation				
	0-30	**30-45**	**45-60**	**60-70**	**70-100**
October	29%	31%	30%	28%	27%
November	18%	22%	19%	18%	18%
December	10%	13%	9%	9%	9%
January	100%	100%	100%	100%	100%
February	96%	96%	97%	95%	93%
March	92%	95%	94%	90%	87%
April	91%	93%	93%	85%	80%
May	90%	91%	88%	78%	72%
June	81%	83%	82%	71%	63%
July	68%	72%	72%	62%	55%
August	55%	58%	59%	51%	46%
September	41%	44%	44%	39%	36%

7.2.9.8 *ORO*

Beginning-of-month (*BoM*) storage and end-of-previous-September (*PrevSept*) storage in Lake Oroville are used in the procedure for setting initial SWP Table A allocations (see Section 7.2.9.3).

7.2.9.9 *SL_SWP*

BoM storage in SWP San Luis is used in the procedure for setting initial SWP Table A allocations (see Section 7.2.9.3) and for adjusting allocations based on an assessment of the Delta export capacity (see Section 7.2.9.4).

7.2.10 COA

COA (1986) obligates the CVP and SWP to coordinate their operations to meet the Delta water quality standards defined in SWRCB Decision 1485. The agreement establishes a framework with which the projects will operate to ensure that both CVP and SWP receive an equitable share of the Central Valley's available water. The agreement established a formula for sharing the obligation of providing water to meet water quality standards and other in-basin uses (IBUs). This formula is set up in SacWAM in the Data Tree structure under *Other Assumptions\Ops\COA*, but is controlled through *User Defined LP Constraints* and is thus summarized in Section 8.4. SacWAM implements the COA accounting procedure in each month as a post-process based on the previous month's result values.[18] It applies the sharing obligations as a transfer of project (SWP or CVP) storage within San Luis Reservoir.

7.2.11 Mokelumne

In SacWAM, all state variables associated with Mokelumne River operations, other than IFRs, are located under *Ops\Mokelumne*.

[18] It is possible to implement the COA dynamically in the same manner as CalSim, where the accounting is handled by the LP within each time step. However, initial attempts to do so resulted in model instabilities due to the use of integer variables applied in the context of change in reservoir storages.

- Mokelume
  - Camanche Flood Control
  - EBMUD Deficiency
  - JVID
  - NSJWCD

7.2.11.1 *Camanche Flood Control*

Pardee and Camanche Reservoirs, located on the Mokelumne River, are owned and operated by EBMUD. The USACE flood-control agreement with EBMUD requires that a combined reservation of up to 200 TAF be maintained in Pardee and Camanche Reservoirs from September 15 to July 31. However, up to a maximum of 70 TAF of this flood-control reservation may be transferable to available space in PG&E's Salt Springs and Lower Bear Reservoirs. The following sections describe state variables relating to flood space requirements for Pardee and Camanche Reservoirs.

- Camanche Flood Control
  - CamancheAprilStorage
  - FloodSpaceAdjustmentforPreRelease
  - FloodSpaceRequirement
  - MokFNFthruJuly
  - NonTransferableFloodSpace
  - PreReleaseofOctFloodWater
  - RainFloodSpaceRqment
  - SnowFloodSpaceRqment
  - TransferableRainFloodSpace
  - TransferableSnowFloodSpace

CamancheAprilStorage

The state variable *CamancheAprilStorage* is the previous April's storage in Camanche Reservoir. The variable is updated each April. The variable is used to determine releases from Pardee Reservoir to maintain thermal stratification in Camanche Reservoir. The variable is not related to flood control requirements, but is contained here for convenience.

MokFNFthrJuly

The state variable *MokFNFthruJuly* is the sum of the unimpaired monthly flows for the Mokelumne River at Mokelumne Hill from the current month (beginning in March) through July. This variable is used in the determination of flood space requirements during the snowmelt season.

RainFloodSpaceRqment

The state variable *RainFloodSpaceRqment* is the rain-flood reservation for Pardee and Camanche Reservoirs, combined, including any transferable space. The monthly requirements are constant from year to year.

SnowFloodSpaceRqment

The state variable *SnowFloodSpaceRqment* is the snowmelt-flood reservation in Pardee and Camanche Reservoirs, including any transferable space. The requirements depend on the natural runoff into Camanche Reservoir from the current date through July 31.

NonTransferableFloodSpace

The state variable *NonTransferableRainFloodSpace* is the flood space that must be maintained in Pardee and/or Camanche Reservoirs and cannot be transferred to upstream PG&E reservoirs. The variable is used to calculate the transferable flood space.

TransferableRainFloodSpaceRqment

The state variable *TransferableRainFloodSpaceRqment* is the reduction in the rain-flood reservation in Pardee and Camanche Reservoirs because of available space in PG&E's upstream reservoirs: Lower Bear Reservoir and Salt Springs Reservoir.

TransferableSnowFloodSpace

The state variable *TransferableSnowFloodSpace* is the reduction in the snowmelt-flood reservation in Pardee and Camanche reservoirs because of available space in PG&E's upstream reservoirs: Lower Bear Reservoir and Salt Springs Reservoir.

PreReleaseofOctFloodWater

Flood space requirements for Pardee and Camanche reservoirs are zero from July 31 through September 15, but subsequently increase to 180 TAF by the end of October. In wetter years, this may result in excessive reservoir spills in SacWAM's simulation. The state variable *PreReleaseofOctFloodWater* is used to gradually release water from storage during the summer months and avoid water spills caused by drawdown in October for flood control. For the months of July, August, and September the value of *PreReleaseofOctFloodWater* is one quarter of the October *RainFloodSpaceRqment.* This value was determined from inspection of recent historical reservoir operations.

FloodSpaceAdjustmentforPreRelease

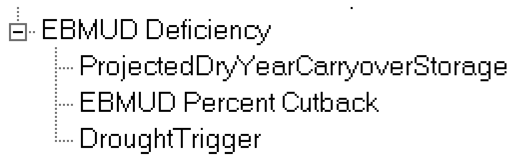
The state variable *FloodSpaceAdjustmentforPreRelease* is the cumulative amount of water that must be released in July, August, and September to minimize reservoir spills in October. It is calculated as the cumulative value of *PreReleaseofOctFloodWater.* It is used to adjust the flood control diagram as a mechanism of forcing additional releases of water from storage.

FloodSpaceRequirement

The state variable *TransferableSnowFloodSpace* is the combined flood reservation in Pardee and Camanche Reservoirs. It is initially calculated as the *RainFloodSpaceRqment* plus *SnowFloodSpaceRqment* less *TransferableRainFloodSpaceRqment less TransferableSnowFloodSpace.* This volume is subsequently adjusted to force prerelease of water that would otherwise spill in later months (*FloodSpaceAdjustmentforPreRelease*).

7.2.11.2 *EBMUD Deficiency*

The following sections describe state variables relating to imposed deficiencies on EBMUD customer demands.



ProjectedDryYearCarryoverStorage

EBMUD adopted its first Water Supply Availability and Deficiency Policy in 1985. Beginning in 1989, EBMUD revised this policy so as to limit deficiencies to a maximum of 25 percent of total customer demand. In 2010, with the adoption of Policy 9.03, the maximum deficiency was reduced to 15 percent, based on the development of new dry-year supplies. In April of each year, EBMUD forecasts its total carryover storage at the end of the water year. If total carryover storage is projected to be less than 500 TAF, customer deficiencies may be imposed.

In SacWAM, the state variable *ProjectedDryYearCarryoverStorage* is a forecast of total carryover storage based on the previous month storage in Pardee, Camanche, and EBMUD's terminal reservoirs; and on the forecasted unimpaired flow at Mokelumne Hill, less river diversions, less Mokelumne Aqueduct draft, less evaporative losses, less groundwater seepage losses, less the MFR at Woodbridge (USGS 11325500).

EBMUD Percent Cutback

The state variable *EBMUD Percent Cutback* is the percent deficiency imposed on deliveries to EBMUD. If the *ProjectedDryYearCarryoverStorage* is greater than 500 TAF, there is no deficiency (*EBMUD Percent Cutback* = 0). Between 450 TAF and 500 TAF carryover storage, deficiencies increase linearly from zero to 15 percent. Between 300 TAF and 450 TAF carryover storage, deficiencies increase linearly from 15 to 25 percent. A larger deficiency is simulated in SacWAM, as the dry-year supply available as part of the Freeport Regional Water Project has currently not been implemented.

Deliveries through the transmission link connecting the Mokelumne Aqueduct to demand unit U_EBMUD are constrained using WEAP's *Maximum Flow Percent of Demand* property, which is set equal to (100- *EBMUD Percent Cutback*).

DroughtTrigger

The state variable *DroughtTrigger* is a flag used to indicate delivery deficiencies. It is determined in April based on *EBMUD Percent Cutback*.

7.2.11.3 *Jackson Valley Irrigation District*

Jackson Valley ID, located in southwest Amador County, provides water for irrigation and M&I use in Jackson Valley. District facilities include Jackson Dam, which impounds Lake Amador, an associated hydro-electric plant, and the Lake Amador Resort Area WTP. Jackson Valley ID has rights to store up to 36 TAF of Jackson Creek flows. The district may divert flows to Lake Amador between November and May at a maximum rate of 110 cfs. However, because of reservoir capacity constraints, the district typically uses about 10 TAF of this right. Additionally, Jackson Valley ID has rights to divert up to 3.85 TAF from the Mokelumne River at a diversion rate of 50 cfs. Under an agreement with EBMUD, Mokelumne River water is delivered to Jackson Valley ID by gravity from the north arm of Pardee Reservoir to Lake Amador. The district requests and usually receives 3.85 TAF annually from EBMUD. However, if the elevation in Pardee Reservoir falls below 550 feet, equivalent to approximately 161 TAF, deliveries to the district are no longer possible.

PardeeElevFlag

The state variable *PardeeElevFlag* is used to determine whether deliveries from Pardee Reservoir to Jackson Valley ID are possible. The variable is assigned a value of 0 when the beginning of month storage in Pardee Reservoir is below 161 TAF; otherwise the variable is set equal to 1.

PrevDemand

The state variable *PrevDemand* is the previous month water demand based on Jackson Valley ID's annual water right of 3.85 TAF and recent historical monthly delivery patterns.

Shortage

The state variable *Shortage* tracks shortages in deliveries to Jackson Valley ID from Pardee Reservoir for the current water year based on cumulative monthly demand and cumulative deliveries.

In SacWAM, the *Maximum Diversion* property on the diversion arc from Pardee Reservoir to Lake Amador is set to the minimum of 50 cfs multiplied by *PardeeElevFlag* and the monthly demand plus any delivery shortage (*Shortage*) in the current water year.

7.2.11.4 *NSJWCD*

Cumulative Deliveries

North San Joaquin WCD (demand unit A_60N_NA3) includes approximately 157,000 acres east of the City of Lodi in eastern San Joaquin County. The service area covers land on both banks of the Mokelumne River, stretching from Dry Creek in the north to the Calaveras River and the boundary with Stockton East WD to the south.

In 1956, North San Joaquin WCD was issued a temporary water right (Permit 10477) as part of Decision 858 (D-858). Permit 10477 is for the temporary appropriation of up to 20 TAF of water from the lower Mokelumne River that is surplus to EBMUD's needs with a diversion season of December 1 to July 1. Through an agreement between both districts, EBMUD stores up to 20 TAF of water in the average to wettest years for delivery to North San Joaquin WCD during the irrigation season. The maximum diversion rate is 80 cfs. Historically, North San Joaquin WCD has used up to 9.5 TAF of water under Permit 10477. However, current demand for Mokelumne River water within the district service area is only approximately 3 TAF (Reclamation, 2014b).

In SacWAM, the state variable *CumulativeDeliveries* tracks annual water deliveries from February through September. Deliveries to the district are restricted using the *Maximum Flow Volume* property on the transmission link from the Mokelumne River to A_60N_NA3. The flow is restricted to the months of December through June and to 20 TAF less the previous month's deliveries (i.e., *CumulativeDeliveries*). The maximum flow rate is 80 cfs.

7.2.12 Contracts

The logic provided under the Contracts branch allows CVP Settlement Contractors to “move” unused water from non-critical to non-critical months and from critical months to non-critical months. Typically, contracts provide for two separate volumes of water. The first is to be used during April, May, June, September, and October. The second volume is to be used during July and August. Water that is unused in April-June can be used during September and October. Unused water from July and August can be used in September and October.

7.2.13 Cosumnes

The Cosumnes River watershed covers parts of El Dorado, Amador, and Sacramento Counties. The upper watershed, east of Highway 49, divides into the watersheds of the North, Middle, and South Forks of the Cosumnes River. Sly Park Reservoir is the only major storage facility in the upper watershed. Located on Camp Creek, a tributary of the North Fork Cosumnes River, the reservoir has a storage capacity of 41 TAF and supplies water to El Dorado ID. Sly Park Dam, which impounds Jenkinson Lake on Sly Park Creek, was constructed by Reclamation in 1955 as part of the Sly Park Unit of the CVP. The unit was transferred to El Dorado ID in 2003. Associated facilities include the Camp Creek Diversion Dam and tunnel connecting Camp Creek to Jenkinson Lake, and the Camino Conduit which delivers water from Jenkinson Lake to the El Dorado ID service area.

7.2.13.1 *AvailableInflow*

The *AvailableInflow* state variable represents the combined flow of Sly Park Creek to Jenkinson Lake and Camp Creek above the diversion dam. It is equal to the sum of inflow timeseries read from SACVAL_Headflows.csv for I_JNKSN and I_CMP001.

7.2.13.2 *EIDAllocation*

The *EIDAllocation* state variable represents the annual allocation of water from Jenkinson Lake to El Dorado ID as a fraction of the annual water demand. Deliveries through the transmission link connecting the Camino Conduit to the district are constrained using the *Maximum Flow Percent of Demand* property, which is set equal to *EIDAllocation*. The *EIDAllocation* varies from zero to one, depending on the storage in Jenkinson Lake, the forecasted inflow through the end of the water year, target carryover storage, and water demands. The allocation is determined in March based on perfect foresight of future inflows.

7.2.13.3 *ForecastWaterSupply*

The *ForecastWaterSupply* state variable is the sum of March through September inflows to Jenkinson Lake and Camp Creek Diversion Dam, i.e., the sum of *AvailableInflow*.

7.2.14 Folsom Flood Curve

The *Folsom Flood Curve* is based on the recently updated flood space diagram whereby between 400 and 600 TAF of flood space is specified, depending on creditable flood space in three upstream reservoirs—French Meadows (*FrenchM_FloodSpace*), Hell Hole (*HellH_FloodSpace*), and Union Valley (*UnionV_FloodSpace*). (*UpperAmer_CredSpace* sums the three to get the total upstream creditable space.) For purposes of computing creditable space, French Meadows can have a maximum of 45 TAF, Hell Hole can have a maximum of 80 TAF, and Union Valley can have a maximum of 75 TAF. If the maximum 200 TAF of creditable space exists upstream, Folsom's flood space is 600 TAF. If there is 0 TAF of creditable space upstream, Folsom's flood space is 400 TAF. In between, the volume of flood space is interpolated, using the same rules as used in the CalSim II model. The full allowed volume of flood space is operated to in November through February, while flood space is 0 in May and June. The other months reflect a drawdown in the fall and a refill curve in the spring, both of which are also interpolated based on upstream creditable space. Table 7-65 shows the flood curve and flood space values by month. Maximum storage in Folsom is 977 TAF.

Table 7-65 Folsom Flood Space Rules

Month	Flood Curve (TAF)	Flood Space (TAF)
Oct	670-720	257-307
Nov-Feb	377-577	400-600
Mar	583-682	295-394
Apr	800	177
May-June	975	0
July	950	25
Aug	800	175
Sep	760	215

7.2.15 Solano Decree

Clear Lake, located in Lake County northwest of Sacramento, is a source of surface water for irrigated agriculture in Yolo County. The lake is one of the oldest lakes in North America with sediments at least 480,000 years old. In 1914 the Cache Creek Dam was constructed to add additional storage and to control lake releases to Cache Creek. Water released by the dam travels downstream into Yolo County and is used for irrigation by the Yolo County FC&WCD.

Releases of water from Clear Lake are controlled by the Solano Decree, an agreement between Lake and Yolo Counties that was drafted in 1978. The Decree is used to determine the total amount of water available for the entire irrigation season as a function of the lake level on April 1.

The other assumptions in this section are used to determine the lake level at the end of March. If the level is greater than or equal to 7.56 feet Rumsey (a local datum) then the District can divert 150 TAF of water from the Lake. If the lake level is less than 3.22 feet Rumsey then no water is available for release. For lake levels between those thresholds the equations in *RumseyEquation* are used to determine the volume that can be released. The equation is recalculated at the beginning of May using *RumseyAdjEquation*. The amount available in a particular month is calculated using *Monthly Allocation*. *Monthly Allocation* is used to restrict releases from Clear Lake using the *Maximum Hydraulic Outflow* parameter in *Supply and Resources\River\Cache Creek\Reservoirs\Clear Lake\Physical\Maximum Hydraulic Outflow*.

7.2.16 Trinity Import

Trinity River water is imported into the Sacramento River basin through the Clear Creek and Spring Creek tunnels. These transfers are made after minimum IFRs below Lewiston Dam are satisfied and are based on beginning-of-month storage in Trinity Reservoir and Shasta Reservoir. SacWAM offers two methods for setting Trinity River imports: the first reads in a timeseries of historical flows into the Clear

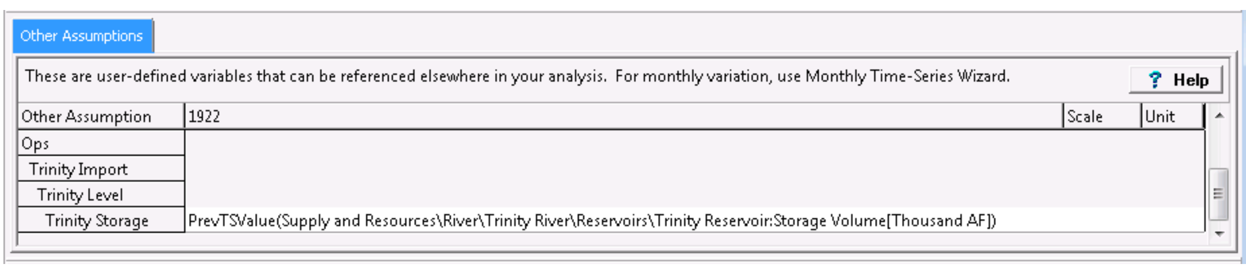
Creek Tunnel and the second uses transfer logic that assesses current storage levels in Trinity and Shasta. The switch that is used to choose between the two options is located in *Other\Calibration Switches\Simulate Trinity Imports* (Section 7.1.1).

The transfer logic is set up using the same approach used by CalSim II (SWP Reliability Report: DWR, 2014e) and is done in such a way as to balance reservoir storages in Trinity and Shasta. That is, imports are reduced when storage in Trinity is low or storage in Shasta is high. Storage levels in the two reservoirs at each time step are read as their respective storage volumes from the previous time step. There are three components to the import logic. The first is based on relative storage in the two reservoirs, as defined by reservoir zones which are based on reservoir levels. The second triggers additional imports when the proportion of storage in each zone is different. The third triggers imports for power generation when Trinity is spilling. The first component exactly replicates the logic in CalSim II. The second and third components replicate the operation in CalSim II, but with different implementation methods appropriate to WEAP. Total imports are the sum of these three components. Component 1 is defined in the requirement *OPS Trinity Import,* and the requirement *OPS Import Spills for Power* pulls in additional water for components 2 and 3.

Imports here are based on a comparison of the relative storages in Shasta and Trinity, defined by whether storage is above or below a series of pre-defined levels.

7.2.16.1 *Trinity Level*

As noted above, the *Trinity Storage* parameter reads the volume of the Trinity Reservoir at the previous time step of the model.



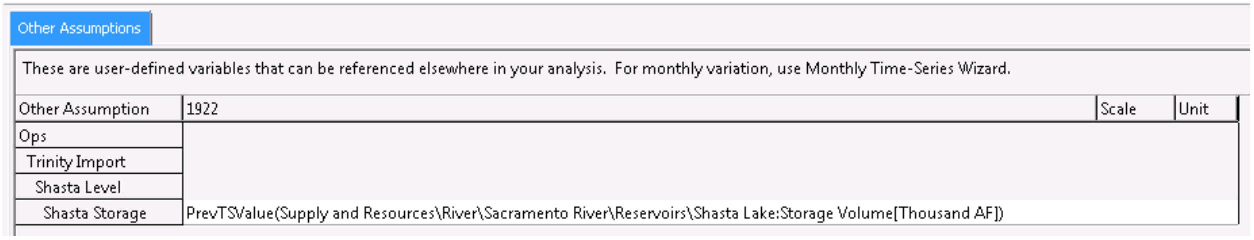
The Trinity storage conditions used to determine transfer amounts are summarized in Table 7-66.

Table 7-66. Trinity Reservoir Storage Levels for Determining Trinity River Imports

<table>
<tr><th rowspan="2">Storage Level</th><th colspan="12">Storage Volume (thousand acre-feet)</th></tr>
<tr><th>Oct</th><th>Nov</th><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th></tr>
<tr><td>Level 0</td><td colspan="12">0</td></tr>
<tr><td>Level 1</td><td colspan="4">700</td><td colspan="2">750</td><td colspan="2">800</td><td>750</td><td colspan="3">700</td></tr>
<tr><td>Level 2</td><td colspan="4">1,200</td><td colspan="2">1,250</td><td colspan="2">1,300</td><td>1,250</td><td colspan="3">1,200</td></tr>
<tr><td>Level 3</td><td colspan="3">1,550</td><td>1,600</td><td>1,650</td><td>1,700</td><td colspan="2">1,800</td><td>1,650</td><td colspan="3">1,550</td></tr>
<tr><td>Level 4</td><td colspan="2">1,975</td><td colspan="2">2,000</td><td>2,050</td><td>2,100</td><td colspan="2">2,200</td><td>2,050</td><td colspan="3">1,975</td></tr>
<tr><td>Level 5</td><td colspan="12">2,500</td></tr>
</table>

7.2.16.2 *Shasta Level*

Similar to the Trinity, the *Shasta Storage* parameter reads the volume of the Trinity Reservoir at the previous time step of the model.



Other Assumption	1922	Scale	Unit
Ops			
Trinity Import			
Shasta Level			
Shasta Storage	PrevTSValue(Supply and Resources\River\Sacramento River\Reservoirs\Shasta Lake:Storage Volume[Thousand AF])		

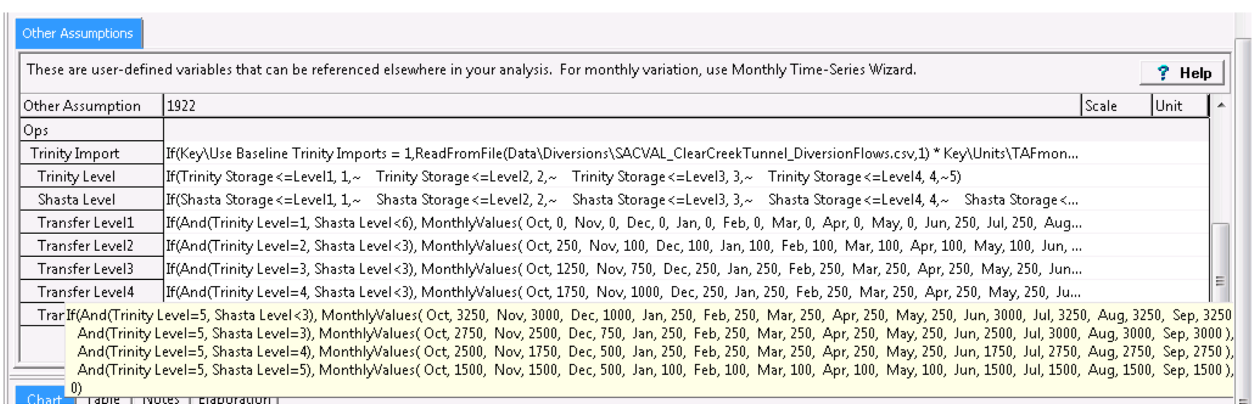
The level of the Shasta Reservoir is the other determining factor (along with Trinity Reservoir storage) in importing water from Trinity Reservoir to the Sacramento Basin. Shasta levels used in determining imports are summarized in Table 7-67.

Table 7-67. Shasta Reservoir Storage Levels for Determining Trinity River Imports

<table>
<tr><th rowspan="2">Shasta Level</th><th colspan="12">Storage Volume (thousand acre-feet)</th></tr>
<tr><th>Oct</th><th>Nov</th><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th></tr>
<tr><td>Level 0</td><td colspan="12">0</td></tr>
<tr><td>Level 1</td><td colspan="6">1600</td><td>2200</td><td colspan="2">2400</td><td>2200</td><td>2100</td><td>1900</td></tr>
<tr><td>Level 2</td><td colspan="6">2000</td><td>2800</td><td>3000</td><td>2900</td><td>2800</td><td>2500</td><td>2300</td></tr>
<tr><td>Level 3</td><td colspan="5">2400</td><td>2500</td><td>3200</td><td>3500</td><td>3300</td><td>3200</td><td>3000</td><td>2800</td></tr>
<tr><td>Level 4</td><td colspan="5">3000</td><td>3200</td><td>3800</td><td>4200</td><td colspan="2">3800</td><td>3600</td><td>3400</td></tr>
<tr><td>Level 5</td><td>3749</td><td colspan="2">3149</td><td>3399</td><td>3799</td><td>4299</td><td>4529</td><td>4550</td><td colspan="2">4399</td><td>4199</td><td>3899</td></tr>
<tr><td>Level 6</td><td colspan="12">4600</td></tr>
</table>

7.2.16.3 *Transfer LevelX*

Whether or not water is transferred from Trinity Reservoir to the Sacramento basin in a given month is determined by Trinity and Shasta storage levels as presented above. The Transfer Level parameters correspond to Trinity Storage levels. For each Transfer Level, there is an *if* statement that determines the outcome for the different combinations of reservoir levels.



Other Assumption	1922	Scale	Unit
Ops			
Trinity Import	If(Key\Use Baseline Trinity Imports = 1,ReadFromFile(Data\Diversions\SACVAL_ClearCreekTunnel_DiversionFlows.csv,1) * Key\Units\TAFmon...		
Trinity Level	If(Trinity Storage<=Level1, 1,~ Trinity Storage<=Level2, 2,~ Trinity Storage<=Level3, 3,~ Trinity Storage<=Level4, 4,~5)		
Shasta Level	If(Shasta Storage<=Level1, 1,~ Shasta Storage<=Level2, 2,~ Shasta Storage<=Level3, 3,~ Shasta Storage<=Level4, 4,~ Shasta Storage<...		
Transfer Level1	If(And(Trinity Level=1, Shasta Level<6), MonthlyValues(Oct, 0, Nov, 0, Dec, 0, Jan, 0, Feb, 0, Mar, 0, Apr, 0, May, 0, Jun, 250, Jul, 250, Aug...		
Transfer Level2	If(And(Trinity Level=2, Shasta Level<3), MonthlyValues(Oct, 250, Nov, 100, Dec, 100, Jan, 100, Feb, 100, Mar, 100, Apr, 100, May, 100, Jun, ...		
Transfer Level3	If(And(Trinity Level=3, Shasta Level<3), MonthlyValues(Oct, 1250, Nov, 750, Dec, 250, Jan, 250, Feb, 250, Mar, 250, Apr, 250, May, 250, Jun...		
Transfer Level4	If(And(Trinity Level=4, Shasta Level<3), MonthlyValues(Oct, 1750, Nov, 1000, Dec, 250, Jan, 250, Feb, 250, Mar, 250, Apr, 250, May, 250, Ju...		
Trar	If(And(Trinity Level=5, Shasta Level<3), MonthlyValues(Oct, 3250, Nov, 3000, Dec, 1000, Jan, 250, Feb, 250, Mar, 250, Apr, 250, May, 250, Jun, 3000, Jul, 3250, Aug, 3250, Sep, 3250 And(Trinity Level=5, Shasta Level=3), MonthlyValues(Oct, 2750, Nov, 2500, Dec, 750, Jan, 250, Feb, 250, Mar, 250, Apr, 250, May, 250, Jun, 2500, Jul, 3000, Aug, 3000, Sep, 3000), And(Trinity Level=5, Shasta Level=4), MonthlyValues(Oct, 2500, Nov, 1750, Dec, 500, Jan, 250, Feb, 250, Mar, 250, Apr, 250, May, 250, Jun, 1750, Jul, 2750, Aug, 2750, Sep, 2750), And(Trinity Level=5, Shasta Level=5), MonthlyValues(Oct, 1500, Nov, 1500, Dec, 500, Jan, 100, Feb, 100, Mar, 100, Apr, 100, May, 100, Jun, 1500, Jul, 1500, Aug, 1500, Sep, 1500), 0)		

Table 7-68 shows the combinations of Trinity and Shasta storage levels (detailed in Table 7-66 and Table 7-67, respectively) that lead to various transfer amounts.

Table 7-68. Trinity River Imports

Trinity Storage Level	Shasta Storage Level	Clear Creek Tunnel Flow (cfs)											
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Level 1	< Level 6	0								250			
	Level 6	0											
Level 2	< Level 3	250	100							250	1,500		1,000
	Level 3	250	100							250	1,250		1,000
	Level 4	250	100							250	1,000		750
	Level 5	250	0							250	750		500
	Level 6	0											
Level 3	< Level 3	1,250	750	250						1,250	2,500		1,750
	Level 3	1,000	500	250						1,000	2,250		1,500
	Level 4	750	500	250						750	1,750		1,500
	Level 5	750	250	100						750	1,500		1,000
	Level 6	0											
Level 4	< Level 3	1,750	1,000	250						1,750	3,250		
	Level 3	1,500	750	250						1,500	2,500		
	Level 4	1,250	500	250						1,250	2,000		
	Level 5	750	500	100						750	1,500		
	Level 6	0											
Level 5	< Level 3	3,250	3,000	1,000	250					3,000	3,250		
	Level 3	2,750	2,500	750	250					2,500	3,000		
	Level 4	2,500	1,750	500	250					1,750	2,750		
	Level 5	1,500	1,500	500	100					1,500			
	Level 6	0											

7.2.16.4 *Shasta at Flood Pool*

In situations when Shasta is at the flood curve in the previous month, the import amount from Table 7-68 is reduced by 50% to conserve storage in Trinity as expressed in *Shasta at Flood Pool*.

7.2.16.5 *Imports of Trinity spills*

This IFR is controlled as a Flow Requirement Object (*OPS Import Spills for Power*) on the Clear Creek tunnel.

In months that Trinity Reservoir is at its flood curve, water that would otherwise have spilled is imported to the greatest extent possible, so that power can be generated in the Francis Carr Powerhouse at the end of the Clear Creek Tunnel. This volume is computed by taking the previous month's storage volume summed with the current month's inflow, and subtracting downstream flow requirements and imports triggered under component 1. Any remaining volume above the flood pool is imported if there is capacity in the Clear Creek Tunnel.

7.2.17 Hodge

The 1987 Hodge decision set diversion limits on pumping at Fairbairn WTP to the City of Sacramento, based on flow in the American River at that location. If flows (*Hodge flow*) are below the thresholds (*Hodge threshold*), a diversion limit is applied at the Fairbairn WTP (see Table 7-69 for thresholds and diversion limits). In cases where demands are greater than the diversion limit, additional diversions above the limit are diverted at the City's Sacramento River WTP instead. A maximum diversion of 310 cfs represents the physical capacity of the plant.

Table 7-69. Hodge Decision Flow Thresholds and Pumping Limits

Month	Threshold Flow at Fairbairn (cfs)	Diversion Limit at Fairbairn WTP (cfs)
Oct	1,879	100
Nov-Dec	2,000	100
Jan-Feb	2,000	120
Mar-May	3,000	120
June	3,000	155
Jul-Aug	1,750	155
Sep	1,750	120

7.2.18 Contra Costa WD

Contra Costa WD operates the Los Vaqueros Reservoir and Delta intakes at Rock Slough, Old River, Victoria Canal, and Mallard Slough. Los Vaqueros is an offstream reservoir that is operated to improve water quality and provide emergency storage for district customers. Los Vaqueros and Contra Costa WD operations are not fully dynamic in SacWAM, instead pumping at the Delta intakes is fixed to the same operation as the CalSim II model for the upcoming Environmental Impact Statement on Los Vaqueros Enlargement. Other aspects of the operation (Los Vaqueros fills and releases, and deliveries) adjust dynamically to meet demand as the first priority and also maintain storage in Los Vaqueros. SacWAM has values for Contra Costa WD's CVP contract (*CVP_WR*) and Los Vaqueros water right (*LV_WR*), but because the intake operations are fixed to CalSim II these values are not used in the model and pumping is not explicitly split between these two sources of water. SacWAM does not include transfers, so in cases where demands were met in CalSim II based on transfers, the full Contra Costa WD demands will not be met and Los Vaqueros storage will be lower than CalSim II.

SacWAM includes maximum capacities for the intakes and pipelines in the system (*Rock_Slough_max, Old_River_max, Victoria_Canal_max, OR_pipeline_max, LV_fill_max*) which are based on physical capacities and no-fill/no-diversion rules consistent with the biological opinions for the Reservoir (*Feb_Nofill, NoDiv_NoFill*). These include no-fill periods of March 15 to May 31 and 0-15 days in February based on Los Vaqueros storage conditions. No-fill and no-diversion rules are suspended when Los Vaqueros storage is at or below emergency pool levels (*Emergency Pool*). Emergency pool levels are 40 TAF when the Sacramento Valley WYT is Dry or Critical, and 70 otherwise. Reservoir releases are also constrained to not reduce storage below these levels (*Max_release_est*). Contra Costa WD's Mallard Slough intake is in SacWAM but is not used (*Mallard Slough*). Timeseries from CalSim II are read in and used to fix intake pumping (*RS timeseries, OR and VC timeseries*) and timeseries are read in for Los Vaqueros fills and releases but these are not currently used in the model (*LV Fill timeseries, LV Rel timeseries*). Intake pumping is set through the requirements *OPS RS pumping* and *OPS OR Pipeline pumping*. The timeseries are also applied as constraints under the *CCWD* User Defined LP Constraints (UDC) branch. Lastly, Kellogg Creek, which flows into and out of Los Vaqueros has a minimum IFR of 5 cfs or inflow, whichever is less.

7.2.19 Freeport

The Freeport Water Supply Project supplies Sacramento County WA and EBMUD from a point of diversion on the Sacramento River approximately 9 miles below the American River confluence. The project enables EBMUD to take delivery of CVP water to meet a portion of its drought year water demands. The CVP contract allows EBMUD to divert up to 133,000 acre-feet of American River water each year with a total not to exceed 165,000 acre-feet in 3 consecutive years. This diversion can only occur in drought years when EBMUD's total system storage is forecast to be less than 500,000 acre-feet. The maximum diversion rate is 100 mgd.

Divert

This variable is a trigger for EBMUD diversions based on district storage conditions and the amount of water delivered in the previous 3 years.

Combine_Store

This variable is the sum of previous month storage in Pardee and Camanche reservoirs.

FPT_Diversion

This variable is the dry year deficiency that is imposed on EBMUD customers based on forecasted carryover storage in district reservoirs.

7.2.20 TrinityShasta_balancing

An additional component of imports is based on a more precise comparison of how proportionally full the different reservoir zones are in Shasta and Trinity, as opposed to just comparing which zone each reservoir is in. This provides a more precise balancing of reservoir storages and is achieved by setting zone boundaries to those that were computed in CalSim II. In CalSim II, Trinity has a total of 5 zones and Shasta has a total of 6. Imports here are determined by the relative storages in zones 2, 3, and 4 in the two reservoirs, and if Trinity has a larger proportion of storage in the appropriate zone, more imports will be made. This logic is in the branch *TrinityShasta_balancing.*

7.2.21 New Hogan Ops

New Hogan Reservoir was built by USACE in 1964 for flood control, water supply, and recreational purposes. The reservoir has a capacity of 317 TAF, with approximately 165 TAF reserved for flood control during the flood season. Inflows, derived primarily from precipitation, average approximately 150 TAF per year. The Corps operates New Hogan Reservoir when flood releases are required; otherwise, the reservoir is operated by Stockton East WD, which schedules releases from conservation storage. Calaveras County WD diverts water for its Jenny Lind WTP below New Hogan Reservoir. Stockton East WD diverts water downstream of New Hogan Reservoir at Bellota Weir for both agricultural and M&I purposes.

7.2.21.1 *New Hogan Water Supply Index*

The *New Hogan Water Supply Index* is a measure of the April through September available water supply in New Hogan Reservoir. It is calculated, based on perfect foresight, as the sum of end-of-March storage, April through September reservoir inflows, less the carryover storage target, less diversions to the Jenny Lind WTP and to riparian water holders, less estimates for reservoir evaporation and river seepage losses.

7.2.21.2 *New Hogan Carryover Target*

The *New Hogan Carryover Storage Target* defines the carryover storage objective for the current water year based on end-of-March storage.

7.2.21.3 *Allocation_MI_1*

The variable *Allocation_MI_1* is the initial allocation of Calaveras River water for use at Stockton East WD's water treatment plant.

7.2.21.4 *Allocation_Ag*

The variable *Allocation_Ag* is the allocation of Calaveras River water for agricultural purposes.

7.2.21.5 *Allocation_MI_2*

The variable *Allocation_MI_2* is an additional allocation of Calaveras River water for use at Stockton East WD's water treatment plant after agricultural allocations have been determined.

7.2.21.6 *Allocation_MI*

The variable *Allocation_MI* is the final allocation of Calaveras River water for use at Stockton East WD's water treatment plant. It is equal to the sum of *Allocation_MI_1 and Allocation_MI_2.*

7.2.22 Controls

This section implements a series of operational control indicators which show which regulations, permits, and physical capacities are controlling various aspects of CVP and SWP operations. Control is defined when pumping, flow, or storage is equal to the specified maximum limit. Most of the control indicators are binary (0,1), with a few exceptions.

7.2.22.1 *AprMay D1641 cap*

Identifies whether combined CVP and SWP exports are controlled by the D-1641 Pulse Period export cap (1= controlled, 0=not controlled).

7.2.22.2 *AprMayD1641 CVP split*

Identifies whether combined CVP exports are controlled by half of the D-1641 Pulse Period export cap (1= controlled, 0=not controlled).

7.2.22.3 *AprMayD1641 SWP split*

Identifies whether combined SWP exports are controlled by half of the D-1641 Pulse Period export cap (1= controlled, 0=not controlled).

7.2.22.4 *Banks HandS*

Identifies whether Banks pumping plant diversions are at minimum H&S level of 300 cfs (1=at or below H&S, 0=above H&S).

7.2.22.5 *Banks max capacity*

Identifies whether Banks pumping plant diversions are at maximum permit capacity (1=at capacity, 0=below capacity).

7.2.22.6 *CVP San Luis vs Rule*

Amount by which CVP San Luis Reservoir is above (+) or below (-) the rule curve.

7.2.22.7 *DeltaSurplus*

Identifies whether there is Delta Surplus under COA for the CVP and SWP combined (1=Delta Surplus, 0=No Delta Surplus).

7.2.22.8 *DeltaSurplus CVP*

Identifies whether there is Delta Surplus under COA for the CVP (1=Delta Surplus, 0=No Delta Surplus).

7.2.22.9 *DeltaSurplus SWP*

Identifies whether there is Delta Surplus under COA for the SWP (1=Delta Surplus, 0=No Delta Surplus).

7.2.22.10 *EI ratio*

Identifies whether combined CVP and SWP exports are controlled by the D-1641 E/I ratio export cap (1= controlled, 0=not controlled).

7.2.22.11 *EI split CVP*

Identifies whether CVP exports are controlled by half of the D-1641 E/I ratio export cap (not currently implemented).

7.2.22.12 *EI split SWP*

Identifies whether SWP exports are controlled by half of the D-1641 E/I ratio export cap (not currently implemented).

7.2.22.13 *Folsom Flood Pool*

Identifies whether Folsom Reservoir is at its flood pool (i.e. the reservoir is spilling) (1=at flood pool, 0=below flood pool).

7.2.22.14 *Folsom MIFs*

Identifies whether releases from Folsom Reservoir are controlled by (i.e. just meeting) either of the two downstream MFRs (1=at MFR, 0=above MFR). Requirements are D-893 and FMS.

7.2.22.15 *Folsom xD893 MIF*

Identifies whether releases from Folsom Reservoir are controlled by (i.e. just meeting) the D-893 MFR (1=at MFR, 0=above MFR).

7.2.22.16 *Folsom xFMS MIF*

Identifies whether releases from Folsom Reservoir are controlled by (i.e. just meeting) the FMS MFR (1=at MFR, 0=above MFR).

7.2.22.17 *Jones HandS*

Identifies whether Jones pumping plant diversions are at minimum H&S of 800 cfs (1=at H&S, 0=above H&S).

7.2.22.18 *Jones max capacity*

Identifies whether Jones pumping plant diversions are at maximum permit capacity (1=at capacity, 0=below capacity).

7.2.22.19 *MRDO*

Identifies whether Delta outflow is controlled by (i.e. just meeting) the D-1641 MRDO requirement (1=at MRDO, 0=above MRDO).

7.2.22.20 *OMR*

Identifies whether OMR reverse flow is controlled by the OMR RPA maximum reverse flow limit (1=at limit, 0=above limit).

7.2.22.21 *Oroville Flood Pool*

Identifies whether Lake Oroville is at its flood pool (i.e. the reservoir is spilling) (1=at flood pool, 0=below flood pool).

7.2.22.22 *Oroville MIFs*

Identifies whether releases from Lake Oroville are controlled by (i.e. just meeting) one of the three downstream MFRs (1=at MFR, 0=above MFR). MFRs are the High-Flow Channel, Low-Flow Channel, and Verona.

7.2.22.23 *Oroville xHighflow Ch MIF*

Identifies whether releases from Lake Oroville are controlled by (i.e. just meeting) the High-Flow Channel MFR (1=at MFR, 0=above MFR).

7.2.22.24 *Oroville xLowflow Ch MIF*

Identifies whether releases from Lake Oroville are controlled by (i.e. just meeting) the Low-Flow Channel MFR (1=at MFR, 0=above MFR).

7.2.22.25 *Oroville xVerona MIF*

Identifies whether releases from Lake Oroville are controlled by (i.e. just meeting) the Verona MFR (1=at MFR, 0=above MFR).

7.2.22.26 *Rio Vista*

Identifies whether Sacramento River flows are controlled by (i.e. just meeting) the Rio Vista D-1641 flow requirement (1=at requirement, 0=above requirement).

7.2.22.27 *RPA HandS*

Identifies whether combined CVP and SWP exports are at minimum H&S under the BiOp RPAs controlled by the D-1641 EI ratio export cap (1=at H&S, 0=above H&S).

7.2.22.28 *Salinity*

Identifies whether Delta outflow is controlled by (i.e. just meeting) the largest of the D-1641 Salinity requirements (1=at requirement, 0=above requirement).

7.2.22.29 *Shasta Flood Pool*

Identifies whether Lake Shasta is at its flood pool (i.e. the reservoir is spilling) (1=at flood pool, 0=below flood pool).

7.2.22.30 *Shasta MIFs*

Identifies whether releases from Lake Shasta are controlled by (i.e. just meeting) either of the two downstream MFRs (1=at MFR, 0=above MFR). MFRs are at Keswick and Wilkins Slough.

7.2.22.31 *Shasta xKeswick MIF*

Identifies whether releases from Lake Shasta are controlled by (i.e. just meeting) the Keswick MFR (1=at MFR, 0=above MFR).

7.2.22.32 *Shasta xRed Bluff MIF*

Identifies whether releases from Lake Shasta are controlled by (i.e. just meeting) the Red Bluff MFR (not currently implemented, Red Bluff MIF is not in the model).

7.2.22.33 *Shasta xWilkins Slough MIF*

Identifies whether releases from Lake Shasta are controlled by (i.e. just meeting) the Wilkins Slough MFR (1=at MFR, 0=above MFR).

7.2.22.34 *SJR IE ratio*

Identifies whether combined CVP and SWP exports are controlled by the April to May *SJR_EIRatio* export cap (1= controlled, 0=not controlled).

7.2.22.35 *SJR IE split CVP*

Identifies whether combined CVP exports are controlled by half of the April to May *SJR_EIRatio* export cap (not currently implemented).

7.2.22.36 *SJR IE split SWP*

Identifies whether combined SWP exports are controlled by half of the April to May *SJR_EIRatio* export cap (not currently implemented).

7.2.22.37 *SWP San Luis vs Rule*

Amount by which SWP San Luis Reservoir is above (+) or below (-) the rule curve.

7.2.22.38 *Trinity Flood Pool*

Identifies whether Trinity Reservoir is at its flood pool (i.e. the reservoir is spilling) (1=at flood pool, 0=below flood pool).

7.2.22.39 *Trinity MIF*

Identifies whether releases from Trinity Reservoir are controlled by (i.e. just meeting) the Trinity Record of Decision MFR (1=at MFR, 0=above MFR).

7.2.22.40 *UWFE IBU*

Identifies whether under COA, there is IBU or unstored water available for export (UWFE) (1=UWFE, 2=IBU).

7.2.22.41 *X2*

Identifies whether Delta outflow is controlled by (i.e. just meeting) the X2 requirement (1=at requirement, 0=above requirement).

7.3 Valley Floor Hydrology

7.3.1 Calibration Factors

Calibration factors are discussed in Appendix B.

7.3.2 Potential Application Efficiency

The Potential Application Efficiency is based on the concept that the applied water is sufficient to achieve average soil moisture across the least watered quarter of the field equal to field capacity. It represents the upper limit on irrigation efficiency imposed by irrigation technology assumed best management practices.

7.3.3 MiscellaneousET

Miscellaneous ET was introduced in to SacWAM to provide a means of increasing or decreasing crop ET to represent other miscellaneous evaporative losses. It is currently set to zero.

7.3.4 Groundwater

This section contains linear equations that determine stream gains and losses from and to groundwater.

7.3.5 SCS Curve Number

The SCS curve number method is used to calculate runoff from daily precipitation.

7.4 Upper Watersheds Hydrology

7.4.1 SAC

These parameters control some of the hydrologic characteristics of the upper watersheds.

7.4.1.1 *Snow*

Each three-letter code refers to a geography that encompasses multiple catchments. The *FreezePt* and *MeltPt* values for each of these codes are calibrated values that are used to assign freezing and melting points to the associated catchments. The list of codes and associated catchments can be found in the RegionalCalibNames tab of **Upper watershed expressions**, referenced in Table 5-6.

7.4.1.2 *Lower Store*

Catchment values for deep water capacity (*WC*) and deep conductivity (*CLbf*) are contained in *LowerStore*. The same three-letter codes used in the *Snow* parameters are used in the *LowerStore* parameters.

7.4.1.3 *Upper Store*

Parameters include Rf, HC, PfdElev, SWC, and Kc

7.4.2 Conversion

Different data sources use different units. The Other Assumptions under the *Upper Watersheds Hydrology\Conversion* heading contain conversion factors for TAF/month to cfs (*TAF2CFS*) and inches to mm (*in2mm)*.

7.5 Urban Outdoor

The values in this branch pertain to irrigation of residential and commercial landscaping.

7.5.1 Area Factors

Separate scaling factors were calculated for land classified as Residential and as Commercial.

7.5.2 Irrig

Schedule: value of 100 assigned to each month. Thresh: no value entered.

7.6 Conversion

Different data sources use different units. The Other Assumptions under the *Conversion* heading contain conversion factors for inches to mm (*in2mm)*.

7.7 Western Canal Outflow

Under a 1922 agreement between Western Canal WD and Butte Sink landowners, natural flows in Butte Creek are supplemented by releases from the district's Western Canal into the creek to maintain a flow of 200 cfs at the Sanborn Slough intake during the fall and early winter. The variable *Western Canal*

Outflow defines outflow targets based on flows in Butte Creek and recent historical canal deliveries to the creek.

7.8 ANN

To turn ANN on/off, the user needs to assign it a 0 or 1, where 1 turns the ANN on and disables the G-model and 0 leaves the G-model as the default method for calculating flow requirements for Delta salinity. See Sections 7.2.6.1 and 7.2.6.3, respectively, for a description of the G-Model and ANN.

Chapter 8 User-Defined Linear Programming Constraints

The WEAP software determines the allocation of water at each time step using a form of linear programming (LP) known as Mixed Integer Linear Programming (MILP). The MILP problem consists of an objective function and a set of linear constraints. The objective function is defined in terms of priorities (weights) and associated decision variables (e.g., storage, streamflow, deliveries). The linear equations that constrain the values of the decision variables typically relate to system connectivity, physical capacities, and regulatory limits on diversions and storage (e.g., water rights, flood control requirements). WEAP is designed to automatically build the objective function and constraints from its built-in model objects (e.g. rivers, demand nodes, groundwater nodes), each of which are endowed with properties that act as constraints (e.g. reservoir storage capacity, maximum diversion capacity) and/or objectives (e.g. MFRs, water demand, water storage). However, for complex water resource systems additional constraints may be needed. This happens, most frequently, in cases where a decision variable is conditional upon another decision variable. For example, the flow over a weir is dependent on the upstream flow in the river.

User-defined variables may be "state" variables or "decision" variables. The value of state variables are known, or are calculated at the beginning of the time step, prior to solving the water allocation problem. The value of decision variables are determined by the MILP solver. Generally, state variables are defined in SacWAM under *Other Assumptions*.

User-defined variables have one of the following forms:

- DefineLPVariable: A standard LP decision variable (i.e., positive real number).
- DefineIntegerLPVariable(0,1): An integer decision variable that may have a value of zero or one.
- DefineLPVariable(-999999,999999): An LP decision variable with a lower bound of -999,999 and an upper bound of 999,999.

This chapter briefly describes the UDCs implemented in SacWAM. They are described in alphabetical order. Brief background information is presented for each UDC. The section headings correspond to branches in the WEAP data tree. This information supplements material presented in Chapter 7 and addresses many of the same aspects of the model.

8.1 Artificial Neural Network

Operation of CVP and SWP facilities is partially dictated by the need to meet D-1641 water quality objectives for the Delta. DWR has developed an ANN that mimics Delta flow-salinity relationships as simulated in the one-dimensional hydrodynamic and water quality model, DSM2 (Sandhu 1995, Wilbur and Munévar 2001). Inputs to the ANN include Delta inflows, San Joaquin River salinity, Delta Cross Channel (DXC) gate position, and Delta exports and diversions.[19] Values for each of these parameters for

[19] The ANN also uses an indicator of tidal energy.

the previous five months are inputs to the ANN, representing an estimate of the length of memory of antecedent conditions in the Delta. The ANN also needs monthly Delta salinity standards and compliance locations.

DWR's ANN is implemented in SacWAM to determine Delta outflow requirements for salinity control. The ANN does not explicitly compute a flow requirement that SacWAM tries to meet. Rather, it specifies a set of linear relationships between Delta exports and Sacramento River inflows that must be maintained to meet D-1641 Delta water quality standards at four compliance locations (Collinsville, Emmaton, Jersey Point, and Rock Slough). Additionally, the ANN provides salinity estimates for Clifton Court Forebay and Contra Costa WD Los Vaqueros diversion locations (Old River and Victoria Canal). The ANN may also be used to calculate Delta salinity at the various compliance locations for the preceding time step once all Delta flows have been determined.

8.1.1 ANN Input

Simulated data passed to the ANN include previous time step values of combined exports at Banks and Jones pumping plants, Contra Costa WD diversions, and Barker Slough Pumping Plant for the North Bay Aqueduct, Sacramento River flow at Hood, San Joaquin River flow at Vernalis, and Yolo Bypass flow at Lisbon Weir. User-defined decision variables are defined for these flow components to provide a short-hand method of referring to these flow components when calling the ANN. These user-defined decision variables are listed in Table 8-1.

Table 8-1. ANN Inputs

Variable	Variable Type	Description
D409	Decision variable	California Aqueduct and Delta-Mendota Canal combined exports
C400	Decision variable	Sacramento River at Hood (RM 041)
C157	Decision variable	Yolo Bypass at Lisbon Weir (below Putah Creek confluence)
C639	State variable	San Joaquin River at Vernalis
DXC	State variable	Fraction of month that Delta Cross Channel is open
DICU	State variable	Delta island consumptive use
Sac_oth_est	State variable	Delta inflow from Calaveras, Cosumnes, and Mokelumne rivers, Marsh Creek, and Yolo Bypass less diversions at Barker Slough Pumping Plant used for current time step
Sac_oth	State variable	Delta inflow from Calaveras, Cosumnes, and Mokelumne rivers, and Marsh Creek, less diversions at Barker Slough Pumping Plant used for previous time steps
Exp_oth	State variable	Delta diversions by Contra Costa WD and the City of Stockton used for previous time steps
Exp_oth_est	State variable	Estimated Delta diversions by Contra Costa WD and the City of Stockton used for current time step
VernWQ	State variable	San Joaquin River salinity (EC) at Vernalis
int	State variable	Days in month
xx_EC_STD	State variable	Bay-Delta Plan water quality standard for station xx
Line_xx_lo	State variable	Lower range for which ANN is applied for station xx
Line_xx_hi	State variable	Upper range for which ANN is applied for station xx
int	State variable	Station indicator
YearType	State variable	yyy

Key: ANN=Artificial Neural Network; EC=electrical conductivity, RM=river mile.

8.1.2 ANN Output

SacWAM implements export-inflow relationships for salinity control using ANN output that is referenced by the following six UDCs: UDC\ANN\meetJP, UDC\ANN\meetEM, UDC\ANN\meetCO, UDC\ANN\meetRS1, UDC\ANN\meetRS2, and UDC\ANN\meetRS3.

These UDCs have the following form:

QSOD < b + m * *QSacValley*

where:

QSOD = combined flow at Banks and Jones pumping plants

QSacValley = combined flow of Sacramento River at Hood and Yolo Bypass at Lisbon Weir

b and m = coefficients determined by the ANN function AnnLineGenArray.

The coefficients b and m are determined separately for each of the four control stations within the Delta — Collinsville, Emmaton, Jersey Point, and Rock Slough. Due to the highly non-linear flow-salinity relationship at Rock Slough, the ANN calculates three separate sets of coefficients that represent a three-piece linearization of the relationship. This results in six separate constraints for QSOD, one each for Collinsville, Emmaton, and Jersey Point, and three for Rock Slough.

Five types of Delta conditions may exist, as implied by the coefficients returned by the ANN and the resulting export-inflow relationship required to meet D-1641 water quality standards:

- Intercept (b) = 0, and slope (m) <= 0.001: Delta salinity is insensitive to Delta exports, salinity control is not possible, therefore, the inflow-export constraint is relaxed and exports are capped at 1,500 cfs (*export cap*).
- m < 0: the inflow-export constraint is relaxed and exports are capped at 1,500 cfs.
- m > 1: known as negative carriage water, required Delta outflow for salinity control diminished as exports increase, therefore, exports are unconstrained by salinity control requirements.
- -b/m < 15,000 cfs (or 12,000 in dry and critical years): the Sacramento Valley inflow to the Delta for salinity control is greater than 15,000 cfs (or 12,000 cfs) for zero exports, therefore, to prevent the release of large volumes of water from storage to meet salinity requirements, combined project exports are capped at 1,500 cfs, and the inflow-export constraint is relaxed.
- For all other values of b and m, the export-inflow relationship is enforced.

For additional discussion of the ANN, see Section 7.8.

8.2 Contra Costa Water District

In order to fix Contra Costa WD Delta intake pumping to values from the CalSim II model, UDCs are used to fix a maximum value for Rock Slough (*RS*) pumping and the combination of Old River and Victoria Canal pumping (*OR and VC*). UDCs for fixing Los Vaqueros fills and releases are also in this section but are not active in the model at this time. See Section 7.2.18 for more description of Contra Costa WD operations.

8.3 City of Stockton

The City of Stockton has multiple sources of water and conjunctively manages surface water and groundwater to deliver treated water within the metropolitan area. The City purchases treated water from Stockton East WD and also owns and operates its own WTP and associated intake located on the

San Joaquin River near Empire Tract. The UDC *SEWD WTP* limits water supplies from Stockton East WD to the 60 million gallon per day (mgd) capacity of the Joe Waidhofer WTP. Similarly, the UDC *Delta WTP* limits supplies from the City's Delta WTP to its 30 mgd capacity. The UDC *WR1485* further limits diversions from the Delta to be less than the discharge from the Stockton Regional WWTP as required by the City's water right permit and by California Water Code section 1485.

8.4 Coordinated Operations Agreement

The COA, signed in 1986, defines formulae for sharing joint CVP-SWP responsibilities for meeting Delta standards (as the standards existed in SWRCB Water Right Decision 1485 [D-1485]) and other in-basin legal uses of water, and identifies how unstored flow is to be shared between the CVP and SWP. Additional details of COA are discussed in Section 7.2.10.

The implementation of COA in SacWAM requires the model to determine whether there is UWFE that may be shared by the CVP and SWP, or if there is IBU within the Sacramento Valley and Delta that must be met by storage releases from project reservoirs (or import of Trinity River water through the Clear Creek Tunnel). The existence of UWFE or IBU is determined by the UDC *COA Balance* that calculates the difference between project exports and project storage releases:

*UWFE - IBU = DeltaSurplus_CVP +DeltaSurplus_SWP+ CVP_EXP1 + CCWD_EXP1 + SWP_EXP1 + (2/3)*NBA_Art21+ (2/3)*NBA_TableA - StorageRelease_SWP - StorageRelease_CVP + Unused_FS + Unused_SS*

If the releases from project storage exceed project exports from the Delta, then there is IBU in the Sacramento Valley. Conversely, if Delta exports are greater than the change in storage, then there exists unused water for export. SacWAM uses the following definitions for these calculations:

Shasta Storage Release = Sacramento below Keswick - Inflow to Shasta - Spring Creek Tunnel diversion

Folsom Storage Release = American below Nimbus + Folsom South Canal + Folsom Lake diversions - Inflow to Folsom

Whiskeytown Storage Release/Trinity Import = Clear Creek below Whiskeytown + Spring Creek Tunnel diversion – Natural inflow to Whiskeytown Reservoir

Oroville Storage Release = Feather River below Thermalito - Inflow to Lake Oroville - Kelly Ridge Powerhouse flow - Thermalito Afterbay diversions - Power Canal diversions

CVP Delta Exports = Export of CVP water at Jones Pumping Plant + *Unused_SS*

SWP Delta Exports = Export of SWP water at Banks Pumping Water + *Unused_FS* + 2/3*Table A and Article 21 water delivered from the North Bay Aqueduct

The ability of the projects to use their share of water under COA may be limited by the physical and permitted capacities of the pumping plants and by other regulatory constraints. The decision variables *Unused_FS* and *Unused_SS* represent one project's use of the other project's water in instances when either the CVP or SWP cannot export their share of water because of export capacity or regulatory restrictions. The user-defined integer *int_Unused_FS_SS* and the associated pair of UDCs, *int_Unused_FS_SS Eqn1* and *int_Unused_FS_SS_Eqn2*, prevent both *Unused_FS* and *Unused_SS* having non-zero values in the same time step.

Delta outflow is divided into the part that is required to meet regulatory requirements, which is part of IBU, Delta outflow that is surplus to regulatory requirements. Delta outflow is further divided into CVP share (*Delta-Surplus_CVP*) and SWP share (*Delta-Surplus_SWP*).

The user-defined integer, *Int_IBU_UWFE*, and the associated pair of UDCs, *IBU_force* and *UWFE_force*, prevent IBU and UWFE from both having non-zero values in the same time step.

The COA defines sharing formula for dividing UWFE between the two projects and assigning responsibilities for meeting IBU. The CVP is entitled to 55 percent of UWFE and SWP entitled to 45 percent of UWFE. The CVP is responsible for meeting 75 percent of IBU; the SWP is responsible for meeting the remaining 25 percent of IBU. The sharing formula are implemented in SacWAM using the UDCs *COA_CVP* and *COA_SWP* that are reproduced below.

CVP_EXP1 +*CCWD_EXP1* + *Unused_FS* = *StorageRelease_CVP* - 0.75**IBU* + 0.55**UWFE* - *DeltaSurplus_CVP*

SWP_EXP1 + (2/3)* *NBA_Art21* + (2/3)* *NBA_TableA* + *Unused_SS* = *StorageRelease_SWP* - 0.25**IBU* + 0.45**UWFE* - *DeltaSurplus_SWP*

Priorities in SacWAM have been set-up so that the CVP south-of-Delta operations are determined prior to SWP south-of-Delta operations. The UDC *EI Split CVP* prevents the CVP from using more than 50 percent of the available export capacity when the D-1645 export to inflow ratio is binding project operations. Similarly, the UDC *OMR_BO_Actions\OMR Constraints\ShareAvailableExport* prevents the CVP from using more than 50 percent of the available export capacity when export pumping is limited by OMR flow criteria.

8.5 Delta Cross Channel

The DXC is a gated diversion channel off the Sacramento River near Walnut Grove. The channel is operated to improve water quality in the interior and south Delta, and to improve the transfer of water from the Sacramento River to CVP and SWP export pumps in the south Delta. When the gates are open, water flows from the Sacramento River through DXC to the lower Mokelumne River and San Joaquin River. Water from the Sacramento River also flows through Georgiana Slough to the Mokelumne River.

When the DXC gates are open, flows through the channel are determined by the upstream stage in the Sacramento River. The flow may be estimated using the following empirical regression equation:

Q_DXC [cfs] = 0.1896 * *QSac_WG* [cfs] – 36 where:

Q_DXC = Delta Cross Channel flow

QSac_WG = Sacramento River flow at Walnut Grove

D-1641 (SWRCB, 1999) and the NMFS (2009) BiOp specify when the DXC gates must be closed to improve migration of anadromous fish species through the Delta. Additionally, Reclamation procedures call for the gates to be closed when flows in the Sacramento River reach the 20,000 to 25,000 cfs range. For modeling purposes, SacWAM uses a Sacramento River flow threshold of 25,000 cfs for gate closure. The following set of equations are used in SacWAM to disaggregate flows in the Sacramento River into components above and below the flow threshold for gate closure of 25,000 cfs:

$$QSac\_WG = 25{,}000 + SAC\_above - SAC\_below$$

$$SAC\_above < int\_SAC\_above * 999{,}999$$

$$SAC\_below < 999{,}999 - int\_above * 999{,}999$$

The user-defined integer variable *int_above* can either be zero or one. A value of zero indicates that the Sacramento River flow is below the 25,000 cfs threshold by an amount SAC_below. A value of one indicates that the Sacramento River flow is above the threshold by an amount SAC_above.

Finally, flow through the DXC is calculated using the following equation:

$$Q\_DXC = [0.1896*25{,}000 *(1 - int\_above) - 36 *(1 - int\_above) - 0.1896*SAC\_below] * DXC\_fraction$$

where:

DXC_fraction = number of days in the month that the DXC is open, expressed as a fraction.

8.6 Delta Export Constraints

The UDCs under *Delta Export Constraints* implement CVP and SWP Delta pumping limits described in Chapter 7. *Delta Export Constraints* work in conjunction with *Split Exports* (see Section 8.19), such that export limits apply only to the portion that is pumped directly from the Delta (as opposed to exports that may be diverted around/under the Delta through an Isolated Facility).

8.6.1 April May Pulse Period

D-1641 restricts export pumping during a 31-day pulse period in April and May depending on flows in the San Joaquin River at Vernalis. During the pulse period, exports may not exceed 1,500 cfs, or 100 percent of the 3-day running average of Vernalis flow, whichever is greater. In SacWAM, the two UDCs *AprilMayPulse_CVP* and *AprilMayPulse_SWP* restrict CVP and SWP exports from the south Delta to be less than pulse period requirements.

8.6.2 D-1641 EI Ratio

D-1641 requires Reclamation and DWR to comply with an export limit objective to restrict CVP and SWP export rates from the Delta. The E/I ratio is measured as the average 3-day export rate for the SWP

Clifton Court intake and CVP Jones Pumping Plant divided by the estimated average inflow to the Delta over a 3-day or 14-day period. *Delta Exports* are constrained to being less than or equal to *Delta Inflow* multiplied by the export ratio, *ExpRatio*.

8.6.2.1 *Delta Inflow Eqn*

Delta Inflow is defined as a standard LP variable (i.e., must be zero or positive). The UDC *Delta Inflow Eqn* sets the *Delta Inflow* to be equal to the sum of the Sacramento River at Freeport, wastewater discharge from the Sacramento Regional WWTP, San Joaquin River at Vernalis, Calaveras River below New Hogan Dam, Cosumnes River at Michigan Bar, Mokelumne River below Woodbridge, Sacramento Weir spills, Fremont Weir spills, Cache Creek at Rumsey, and South Fork Putah Creek at Interstate 80. This measure of Delta inflow follows that defined in D-1641 (SWRCB, 2000), with the following exceptions:

- SacWAM uses Calaveras River flow below New Hogan Dam rather than flow at Bellota as specified in D-1641.
- SacWAM does not include inflow from miscellaneous streams (Bear Creek, Dry Creek, Stockton Diverting Canal, French Camp Slough, Marsh Creek, and Morrison Creek) as specified in D-1641.

These changes from D-1641 are consistent with how DWR and Reclamation operate the CVP and SWP to meet SWRCB regulatory requirements (Chu, 2016).

8.6.2.2 *EI Split CVP*

SacWAM assumes that available export capacity under the E/I requirement is shared equally between the CVP and SWP, unless one project is unable to pump its share of water. The UDC EI Split CVP restricts CVP exports of the federal share of available Delta water to be less than one-half of the available regulatory export capacity.

8.6.2.3 *EI Split SWP*

No separate limit is set on SWP exports under the E/I ratio as CVP south-of-Delta deliveries have a higher priority in SacWAM than SWP south-of-Delta deliveries. Within each time step, CVP operations are simulated first. The UDC *EI Split SWP* is turned off.

8.6.3 SJR EI Ratio

The NMFS (2009) BiOp established export restrictions to reduce the vulnerability of emigrating Central Valley steelhead within the lower San Joaquin River to entrainment into the channels of the South Delta caused by CVP and SWP export pumping. Under RPA Action IV.2.1, from April 1 to May 31 CVP and SWP exports are restricted to a fraction or a ratio of the San Joaquin River flow at Vernalis. The ratio is based on the San Joaquin River index. Details of the pumping restriction are described in Chapter 7.

The UDC *SJR_EIRatio_Total* restricts combined CVP and SWP exports to be less than the state variable *Other\Ops\ExportOps\SJR_EIRatio\SJ_MaxExp*.

The UDC *SJR_EIRatio_CVP* restricts CVP pumping of the federal share of available Delta water to be less than one-half of *Other\Ops\ExportOps\SJR_EIRatio\SJ_MaxExp*.

8.7 Delta Reverse Flows

The WEAP modeling software does not allow bi-directional flow in rivers. However, there are two channel reaches within the Delta where bi-directional flows must be simulated. The first channel reach is the combined flow in *OMR* [20] between the intake to the DMC/Jones Pumping Plant and the confluence of OMR and San Joaquin River. The second channel reach is flow in the lower San Joaquin River above its confluence with the Sacramento River (*QWest*).

SacWAM uses two parallel river arcs to represent bi-directional flow and an associated pair of equations to restrict flows so that water can move in only one direction during a single time step. The form of the equations is as follows:

$$Q_{Downstream} \leq Integer_{ReverseFlow} * 999{,}999$$

$$Q_{Upstream} \leq 999{,}999 - Integer_{ReverseFlow} * 999{,}999$$

Where $Q_{Downstream}$ is the natural (positive) flow direction, $Q_{Upstream}$ is the reverse flow direction, and $Integer_{ReverseFlow}$ is an integer decision variable that has a value of either 0 or 1. If $Integer_{ReverseFlow}$ equals 0, flow is in the natural direction; reverse flow occurs when $Integer_{ReverseFlow}$ equals 1.

8.7.1 Old and Middle River (OMR)

The user-defined decision variable *OMR Net Flow* represents the net combined flow in the Old and Middle Rivers at Bacon Island at the location of the USGS gauges used for compliance purposes. Net flow is calculated as *OMR Positive Flow* minus *OMR Reverse Flow*. When the integer variable *OMR_Int* has value of 1, there is no reverse flow. During model testing, the requirement that flow in one channel be zero often caused difficulties for the MILP solver. Therefore, these requirements are currently relaxed in SacWAM.

8.7.2 QWest

Qwest is defined as the net westward flow of the San Joaquin River at Jersey Point averaged over a tidal cycle. Under natural conditions Qwest is positive. However, under certain tidal, river inflow, and south Delta export pumping conditions, net reverse flows may occur, i.e., the net flow direction is eastward. Negative values of Qwest occur when Delta diversions and agricultural demands in the south and central Delta exceed the inflow into the central Delta. Qwest is typically positive during wetter water years and always positive in the spring. Qwest is typically negative in the summer of drier years. Qwest criteria are not included in the 1995 Bay-Delta Plan (SWRCB, 1995); however, Qwest criteria have previously been considered as a regulatory parameter for protection of central Delta fish.

In SacWAM, *Qwest* reverse flow is represented as an outflow from the Sacramento River upstream from the confluence. *Qwest* positive flow is represented as the San Joaquin River below the OMR confluence. During model testing, the requirement that flow in one channel be zero often caused difficulties for the MILP solver. Therefore, these requirements are currently relaxed in SacWAM.

[20] SacWAM represents the Old River and Middle River as a single river.

8.8 Delta SOD Channels

Flow requirements for OMR established by USFWS (2008) may limit export pumping from December 15 to June 30. However, SacWAM cannot simulate the tidal hydrodynamics of the south Delta. Instead, the model uses a set of empirical regression equations and a flow balance to determine OMR flows. Hutton (2008) developed flow relationships for south Delta channels based on the following flow balance:

$$OMR = SJR_v + IS_{OR} - SJR_{HOR} - CCF - JPP - CCWD - NCD_{SD}$$

where:

SJR_v = San Joaquin River at Vernalis

SJR_{HOR} = San Joaquin River downstream from Head of Old River

IS_{OR} = Indian Slough at Old River

CCF = Clifton Court Forebay diversion

JPP = Jones Pumping Plant diversion

CCWD = Contra Costa WD Old and Middle River diversion

NCD_{SD} = Net channel depletion in the South Delta

Assuming a linear relationship between San Joaquin River flow at Vernalis and the flow at the Head of Old River, the flow balance can be rewritten as:

$$OMR = A*SJR_v + B*(CCF + JPP + CCWD + NCD_{SD}) + C$$

The value of the coefficients A, B, C, as reported by Hutton (2008), are listed in Table 8-2.

Table 8-2. Split Exports Variables

Barriers		San Joaquin River	Coefficients		
Head of Old River	**Grant-Line Canal**	**at Vernalis (cfs)**	**A**	**B**	**C**
Out	Out	< 16,000	0.471	-0.911	83
Out	Out	16,000 – 28,000	0.681	-0.940	-3008
Out	Out	>28,000	0.633	-0.940	-1644
Out	In	All	0.419	-0.924	-26
In (Spring)	Out/In	All	0.079	-0.940	69
In (Fall)	Out/In	All	0.238	-0.930	-51

8.8.1 Q_SOD

Q_SOD is a user-defined standard LP variable that represents combined diversions and exports from the south Delta. The UDC *SetQ_SOD* determines *Q_SOD* as the sum of the headflows in the California Aqueduct and DMC, CCWD OMR diversions, and south-of-Delta net consumptive use.

8.8.2 Q_IndianSlough

Q_IndianSlough is a user-defined standard LP variable that represents flow from the San Joaquin River through Indian Slough to the Old River, at a point south of the OMR flow compliance location (*Set Q_IndianSlough 2*). The constraint S*et Q_IndianSlough 1* constrains flow through Indian Slough to be equal to (1+coefB)* *Q_SOD* based on the Hutton (2008) relationships described above.

8.8.3 Q_HOR

Q_HOR is a user-defined standard LP variable that represents flow at HOR (*Set Q_HOR 1)*. The constraint *Set Q_HOR 2* constrains flow at HOR to be equal to *coefA* Q_SJR + coefC*, based on the Hutton (2008) relationships described above, where Q_SJR is the flow in the San Joaquin River at Vernalis.

8.9 Delta Salinity

The purpose of the LP variables and UDCs defined under *Delta Salinity* is to calculate the outflow requirement for salinity control. This requirement is needed for the COA balance as it is part of IBU that the CVP and SWP are jointly obligated to meet.

8.9.1 Compliance Stations

The user-defined decision variables *CO*, *EM*, *JP*, *RS1*, *RS2*, and *RS3* represent the outflow required to meet D-1641 water quality standards at Collinsville, Emmaton, Jersey Point, and Rock Slough.[21] The value of these variables are determined by UDCs (s*etCO, setEM, setJP, setRS1, setRS2*, and *setRS3*) using the ANN export to inflow relationship for water quality compliance and a Delta flow balance.

8.9.2 Delta Flow Balance

The required Delta outflow for salinity control is calculated from a flow balance. Components of this flow balance are as follows:

DeltaExports = Diverted inflow to the California Aqueduct and Delta-Mendota Canal

DeltaFlows = Delta inflow from the San Joaquin River, Littlejohn Creek, Calaveras River, Mokelumne River, Kellogg Creek, and Marsh Creek

MiscFlows = Delta diversions/exports at Barker Slough Pumping Plant, Old River Pipeline intakes on the Old River and Victoria Canal, Contra Costa Canal intake on Rock Slough

Net DICU = Net Delta island consumptive use of net channel depletion

8.9.3 Outflow for Salinity Control

The user-define variable *OutflowRequirement* is the net Delta outflow required for salinity control. It is the maximum of the outflow needed for compliance at the individual stations. This is enforced using a set of seven UDCs (*OR eqn1, OR eqn2, OR eqn3, OR eqn4, OR eqn5, OR eqn6,* and *OR eqn7*).

8.10 Feather River Service Area

Two UDCs relate to operation of canals within the FRSA. These are described in the sections below.

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[21] The D-1641 salinity requirement at Rock Slough is represented using three variables because of piecewise linear approximation of the inflow to export relationship for salinity control.

8.10.1 Western Canal Outflow

Based on a 1922 agreement, Western Canal WD supplies water to managed wetlands located in the Butte Sink. After September drainage of rice fields, up to 200 cfs of water is released from the Western Canal to Butte Creek to achieve a flow rate at Sanborn Slough of 250 cfs. From 2000 to 2009, these releases averaged approximately 14 TAF/year.

In SacWAM, the desired Western Canal release is defined by the state variable *Western Canal Outflow*. When the flow in Butte Creek near Chico (USGS gauge 11390000) is less than 15 TAF/month, *Western Canal Outflow* is set to 40 cfs in September, 140 cfs in October, and 30 cfs in November. In all other months the release is set to zero. These flow objectives are imposed by the UDC *Western Canal Outflow* constraint. The release requirements to Butte Creek are modeled using a UDC rather than using WEAP's flow requirement object, in order to limit flows to Butte Creek to the desired target.

8.10.2 Cox Spill

The Joint Board Canal conveys water from the Thermalito Afterbay to four water districts that collectively are known as the Joint Water District: Biggs-West Gridley WD, Butte WD, Richvale ID, and Sutter Extension WD. Excess water in the Joint Board Canal is spilled back to the Feather River through a wasteway known as the Cox Spill. Based on an analysis of canal data from 2000 to 2009 (NCWA, 2014), Cox Spill flows are set at 1.5 percent of the Joint Board Canal diverted inflow. This is equivalent to approximately 9 TAF/year.

8.11 Fix Leaks

WEAP diversion arcs are used in SacWAM to represent canals, channels, and pipelines that deliver water from a stream or river to a demand site or catchment object. For example, the *Foothill WTP* arc connects the Sacramento River to demand sites U_02_SU and U_03_SU, which represent the City of Redding on the west and east bank of the Sacramento River. In certain high flow situations, SacWAM may wish to remove water from the system by diverting water in excess of demand through the *Foothill WTP* arc and out of the model domain.

Five UDCs are used to prevent outflow from the model domain for the following diversion arcs: *Bella Vista* (Pipeline), *Foothill WTP*, *TCC* (Tehama-Colusa Canal), *GCC* (Glenn-Colusa Canal) and *El Dorado Hills WTP*. In this manner, excess water flows to the Delta and leaves the model domain as surplus Delta outflow. A sixth UDC is implemented in the model to prevent Contra Costa WD intake pumping from leaving the system rather than meeting deliveries (*Old River Pipeline*).

8.12 Freeport Regional Water Project

EBMUD undertook the Freeport Regional Water Project in partnership with Sacramento County WA. The project enables EBMUD to take delivery of CVP water to meet a portion of its drought year water demands. The CVP contract allows EBMUD to divert up to 133,000 acre-feet of American River water each year with a total not to exceed 165,000 acre-feet in three consecutive years. This diversion can only occur in years when EBMUD's total system storage is forecast to be less than 500,000 acre-feet. The maximum diversion rate is 100 mgd.

The UDC *Freeport_EBMUD* limits EBMUD's use of Freeport to the user-defined variable *FPT_Diversion* as described in Chapter 7.

8.13 Glenn-Colusa Canal

Glenn-Colusa ID sells district water to the Colusa Basin Drain water users. In SacWAM, these users are represented by demand unit A_08_PA. Water sales are delivered from the Glenn-Colusa Canal. The UDC *Glenn Colusa ID* limits the sale of water to that available to Glenn-Colusa ID under the district's water rights and CVP contract, less the amount of water delivered to district farmers.

8.14 Knights Landing Ridge Cut

The Knights Landing Ridge Cut (Ridge Cut) was constructed to provide an outlet from the Colusa Basin when high Sacramento River stage prevents discharge of excess water through the Knights Landing Outfall Gates. The Ridge Cut, which passes through the Knights Landing Ridge, consists of two dredged channels with a center island. The Ridge Cut has a total width of approximately 400 feet, and a capacity of 15,000 to 20,000 cfs. Floodwater, which would otherwise have ponded between the back levee along the east side of Colusa Basin Drain and higher ground to the west, flows through the Ridge Cut into the Yolo Bypass. The Ridge Cut also provides irrigation water during the summer months. Flows through the Ridge Cut are ungauged; however, DWR estimates flows based on the stage at the Knights Landing Outfall Gates. During the summer, water levels in the Ridge Cut are controlled by a temporary weir at the southern end of the channel to facilitate irrigation diversions.

SacWAM defines the LP variables *CBD* and *KRLC* to represent outflow from the drain to the Sacramento River and flow through the Ridge Cut, respectively. The user-defined decision variable *QSac* represents flow in the Sacramento River below Wilkins Slough at the Navigation Control Point. This flow is divided into two components, *QSac_0* and *QSac_1*, which represent flow up to a 15,000 cfs threshold and the flow above this threshold. SacWAM uses an integer variable, *Int_KLRC*, and a set of equations to divide the flows, as follows:

$$Q_{Sac\_0} <= Int\_KLRC * 999{,}999$$

$$Q_{Sac\_1} <= 999{,}999 - Int\_KLRC * 999{,}999$$

$$Q_{Sac} = Q_{Sac\_0} + Q_{Sac\_1} + 15{,}000 * Int\_KLRC$$

Outflow through the Colusa Basin Drain to the Sacramento River is restricted when flows in the Sacramento River exceed 15,000 cfs.

$$CBD < 999{,}999 – Int\_KLRC * 999{,}999$$

The historical flow through the Ridge Cut is stored in a csv file and assigned to the state variable *KLRCmax*. Under normal, non-flood, operations, flow through the Ridge Cut is constrained to be less than the historical flow, and all remaining flow discharges from the Colusa Basin Drain into the Sacramento River at Knights Landing. An IFR on the Ridge Cut equal to the historical flow is used to achieve the desired operation.

8.15 Los Vaqueros Reservoir

Los Vaqueros Reservoir is an offstream facility owned and operated by Contra Costa WD for water blending purposes and to provide an emergency water supply. The reservoir is filled from district intakes on the Old River and Victoria Canal.

Simulation of Los Vaqueros Reservoir has not been fully implemented in SacWAM. UDCs defined under Los Vaqueros Reservoir simply restrict filling and releasing of water from the reservoir in the same time step.

8.16 Minimum GW Pumping

Typically, SacWAM demand units are supplied with a mix of surface water and groundwater. Surface water is usually assigned the first supply preference and groundwater assigned the second supply preference. In the model, a minimum groundwater pumping fraction acts as a surrogate for representing those lands within the demand unit that are dependent on groundwater – not having access to surface water. The fraction is calculated from DWR's county land use surveys in which each agricultural parcel is assigned a source of water: surface water, groundwater, or mixed. The fraction is set equal to the area of lands supplied by groundwater divided by the total area of irrigated lands. Applied water demands in excess of minimum groundwater pumping are met from surface water and additional groundwater pumping, if necessary.

In cases where SacWAM demand units are supplied from only one surface water transmission link, surface water deliveries are constrained using the WEAP transmission link property *Maximum Flow Percent of Demand.* This is set equal to (1-minimum groundwater pumping factor). In cases where a demand unit is supplied from multiple surface water transmission links, the constraint on surface water use must be imposed using a UDC. The form of the UDC is as follows:

∑(Flow through transmission links) < (1-minimum groundwater pumping factor) * supply requirement

The minimum groundwater pumping factors and supply requirements for each DU are listed under *Demand Sites and Catchments\[DU name*].

8.17 Mokelumne

Pardee and Camanche reservoirs are owned and operated by EBMUD to meet flood control requirements specified in the USACE flood-control manual. These requirements are in place from September 15 to August 1. During this period, required flood space is divided into a rain-flood reservation and a snowmelt flood reservation. The maximum flood control space is 200,000 acre-feet, with a minimum of 130,000 acre-feet of space to be provided in Pardee and Camanche reservoirs. Up to 70,000 acre-feet may be provided by available space in PG&E's Salt Spring and Lower Bear reservoirs, which are located in the upper watershed.

The UDC *FloodControl* requires that the difference between combined Pardee and Camanche storage capacity and the volume in storage is less than the flood space requirement as calculated by the state variable *Other\Ops\Mokelumne\FloodSpaceRequirement*. This is further discussed in Chapter 7.

8.18 OMR BO Actions

OMR Reverse Flow is a user-defined standard LP variable (i.e., must be zero or positive) that represents reverse flow in OMR at the USGS compliance locations adjacent to Bacon Island. The UDC *Set Q_OMR_Final* restricts the reverse flow (i.e., from North to South) to be less than the state variable *Other\OMR and Health and Safety\Q_OMR_ReverseBound*. This is further described in Chapter 7. The UDC *ShareAvailableExport* restricts diversions at Jones (CVP) pumping plant to 50% of available export capacity under the OMR standard (*Other\OMR and Health and Safety\Available Export*), so that available pumping capacity is split equally between CVP and SWP.

8.19 Oroville Fall Operations

October and November flows in the Feather River high-flow channel (i.e., downstream from the Thermalito Afterbay release to the river) are constrained to be less than 4,000 cfs in October and 2,500 cfs in November, except when Oroville is spilling (*Fall release constraint*). This is an operational constraint in place to prevent triggering of increased November to March flow requirements under the 1983 MOU between DWR and CDFW (formerly California Department of Fish and Game). See Section 7.2.3.4 for more description of this operation.

8.20 San Luis Reservoir

San Luis Reservoir is a joint CVP-SWP offstream storage facility used to temporary store project water before delivery to project contractors. In SacWAM, it is represented as two separate reservoirs: *CVP_SanLuis* and *SWP_SanLuis*.

8.20.1 CVP_SanLuis

Water from DMC is delivered to San Luis Reservoir through the O'Neill and Gianelli pumping-generating plants. CVP water from San Luis Reservoir is subsequently released into the San Luis Canal or to the DMC for delivery to CVP contractors. Additionally, the CVP diverts water from the west end of San Luis Reservoir through the Pacheco Tunnel and Pacheco Conduit to supply CVP water service contractors in Santa Clara and San Benito counties.

SacWAM's simulated operations of the CVP share of San Luis Reservoir are driven by the CVP San Luis rule curve. During the fall, winter, and spring the reservoir is filled up to rule curve with a mix of unstored water supplies and storage releases from CVP reservoirs. Subsequently, if additional unstored water supplies exist, the reservoir is filled above rule curve, up to capacity, according to the amount of water available. Lastly, CVP may use any unused State Share of water under COA to fill the CVP share of the reservoir to capacity.

The user-defined variable *CVPSanLuisInt* is an integer variable associated with CVP simulated operations of San Luis Reservoir. The associated UDCs *Fill* and *Release* prevent the reservoir from both filling and draining in the same time step.

8.20.2 SWP_SanLuis

The SWP share of San Luis Reservoir allows DWR to meet peak seasonal SWP demands. DWR stores water in the reservoir when pumping at Banks Pumping Plant exceeds SWP contractor demands, and releases water to the San Luis Canal/California Aqueduct when pumping at Banks Pumping Plant is insufficient to meet these demands.

SacWAM's simulated operations of the SWP share of San Luis Reservoir are driven by the SWP rule curve for the reservoir. During the fall, winter, and spring the reservoir is filled up to rule curve with a mix of unstored water and storage releases from Lake Oroville. Subsequently, if additional unstored water supplies exist, San Luis Reservoir is filled above rule curve, up to the SWP's share of capacity according to the amount of water available. Lastly, SWP may use any unused Federal Share of water under COA to fill the reservoir.

The user-defined variable *SWPSanLuisInt* is an integer variable associated with CVP simulated operations of San Luis Reservoir. The associated UDCs *Fill* and *Release* prevent the reservoir from both filling and draining in the same time step.

8.21 Split Exports

The UDCs under Split Exports disaggregate Delta exports into different flow components. Variables defined under *Split Exports* are referenced by *Delta Export Constraints* (see Section 8.6) and by COA (see Section 8.4).

8.21.1 WaterFix

Flows through Banks and Jones pumping plants are disaggregated for the purposes of implementing D-1641 standards and BiOp requirements under a simulated scenario that includes the Water Fix (i.e., the Delta Tunnels originally envisaged as part of the Bay Delta Conservation Plan (BDCP)). For example, restrictions on Delta pumping in order to satisfy OMR flow requirements and the Export-to-Inflow ratio are applied only to the portion of exports that are derived directly from the Delta. Disaggregated flows consist of a 'through-Delta' component and an 'isolated facility' component. User-defined variables for the various export components are listed in Table 8-3.

Table 8-3. Split Exports Variables

Variable	Description
CA_TD	The portion of flows into the California Aqueduct derived from the Delta
CA_IF	The portion of flows into the California Aqueduct that is diverted around the Delta through the IF
DM_TD	The portion of flows into the DMC derived from the Delta
DM_IF	The portion of flows into the DMC that is diverted around the Delta through the IF
CA_exp	Total flows into the California Aqueduct.
DM_exp	Total flows into DMC
Export_TD	Total combined flows into the California Aqueduct and DMC that come from the Delta
Export_IF	Total combined flows into the California Aqueduct and DMC that are diverted around the Delta through the IF
CC_TD	The portion of Contra Costa Water District diversions derived from the Delta

Key: DMC=Delta-Mendota Canal; IF=Isolated Facility.

8.21.2 North Bay Aqueduct

Water pumped from the Barker Slough Pumping Plant in to the North Bay Aqueduct is a mix of SWP contract water and water right water. User-defined variables for the various water types include: Table A Water, Article 21 Water, Vallejo Permit Water, and Settlement Water. Permit Water and Settlement Water are described below.

In 1998, the Cities of Fairfield, Benicia, and Vacaville filed applications with SWRCB to appropriate a total of 31,620 acre-feet. This water would be wheeled through North Bay Aqueduct facilities. DWR, the City of Vallejo, and others protested these applications. In a subsequent settlement agreement between DWR, Solano County WA, and the three applicants, DWR agreed to deliver up to 31,620 acre-feet to the applicants. This water, known as “settlement water”, is not available when SWRCB Term 91 is in effect.

The City of Vallejo holds a water right (Permit 8993) issued in 1948 for the diversion of up to 31.52 cfs year-round from Cache Slough, primarily for M&I purposes. This is equivalent to a maximum of 22,780 acre-feet per year. Through contracts and agreements, DWR has limited the annual amount of permit water to 17,287 acre-feet. Permit water is senior to SWP water rights, and is not subject to Term 91 curtailments.

8.22 Weirs

Six weirs, all located along the Sacramento River, are included in SacWAM. Flows over these weirs are calculated using a fixed fraction of Sacramento River flow above a defined threshold at each weir location. This requires the use of integer variables to determine flow conditions within the Sacramento River at each weir within the current time step. The values of the integer variables are equal to 1 when flow thresholds are exceeded and equal to zero otherwise. The flow thresholds and fractions of flows above these thresholds that spill over the weirs are presented in Table 8-4.

For each weir, there is a UDC named *Q_[weirname]_HistFix*. This constraint is for testing purposes only and is used to fix weir flows to historical values. These historical values are stored in the file Data\Param\SACVAL_WeirInflows.csv. If this is activated by the model user, all other weir constraints should be deactivated.

Table 8-4. Flow Parameters for Sacramento River Weirs

Weir	Flow Threshold (cfs)	Fraction of Flow Above Threshold to Weir	Integer Variable
Eastside to Butte Basin	90,000	0.73071	Int_eastside
Moulton Weir	60,000	0.33152	Int_moulton
Colusa Weir	30,000	0.76788	Int_colusa
Tisdale Weir	18,000	0.75177	Int_tisdale
Fremont Weir	62,000	0.79808	Int_fremont
Sacramento Weir	73,000	0.87380	Int_sacramento

An example of the implementation of the weir logic is provided by the Eastside weir spills. Floodwaters in the Sacramento River overflow the left bank of the river into Butte Basin at three sites in a reach known as the Butte Basin Overflow Area, or the Butte Basin Reach. The northernmost overflow point is at a degraded levee called the M&T flood relief structure. The second overflow point is the 3Bs natural overflow site. The last overflow point is at another degraded levee known as the Goose Lake flood relief structure. In SacWAM, these 3 structures are simulated as a single weir located downstream from the Sacramento River confluence with Stony Creek. Water spills into the Butte Basin when Sacramento River flows exceed 90,000 cfs. Sacramento River flows upstream from the weir (i.e., *QSac_RM184*) are split in to two components: *QSac_RM184_0* that represents flows up to 90,000 cfs; and *QSac_RM184_1* that represents the incremental flows above 90,000 cfs.

QSac_RM184 = QSac_RM184_0 + QSac_RM184_1

QSac_RM184_0 <= 90,000 + 1

The weir equations are set up so that the integer variable, *Int_eastside*, is forced to a value of one when flows are greater than 90,000 cfs, or a value of zero when flows are less than this threshold.

*QSac_RM184_0 >= Int_eastside * 90,000*

*QSac_RM184_1 <= Int_eastside * 999,999*

Above the weir threshold, flows over the weir, *Q_Overflow*, are a function of the incremental flow *QSac_RM184_1*.

Q_*Overflow* = 0.73071 * *QSac_RM184_1*

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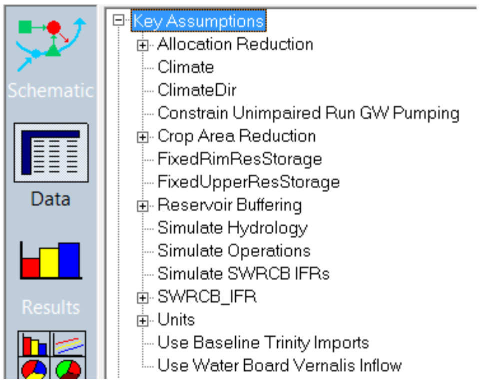
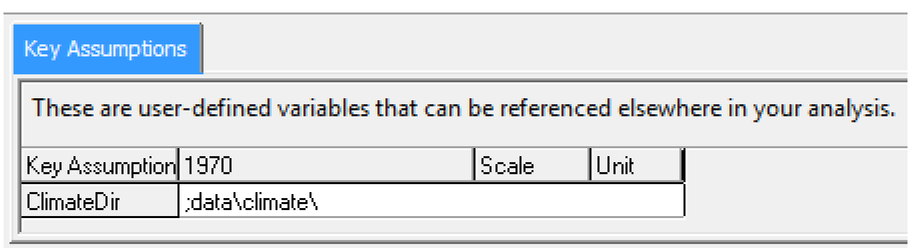
Chapter 9 Key Assumptions

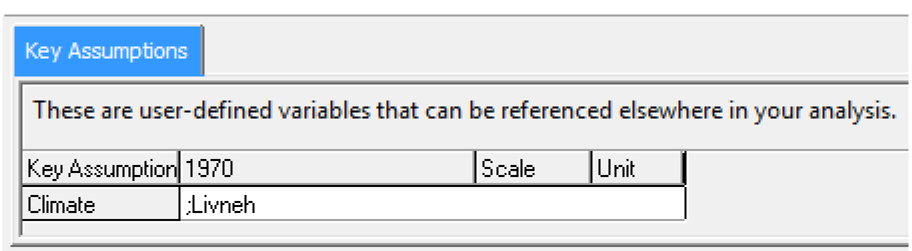
SacWAM was designed to provide flexibility in simulating system operations through the use of a set of controls or model settings. These controls can be accessed in the WEAP Data view under Key Assumptions. This chapter describes each control.



9.1 ClimateDir and Climate

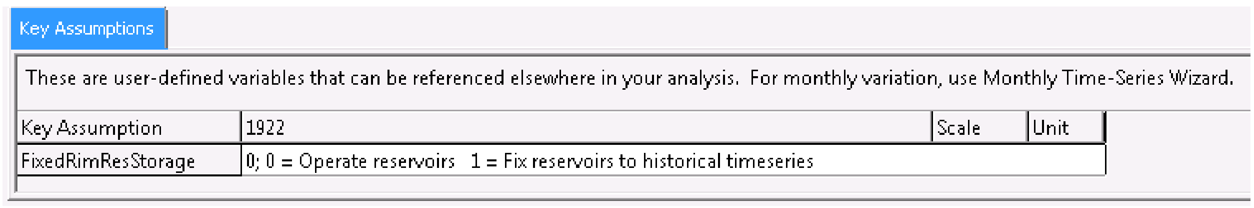
There are two Key Assumptions that are used to specify climate input data that will be used during model simulation. The *ClimateDir* parameter specifies the location or path of the climate data within the model directory. Currently, this parameter is set at "data\climate\" and likely does not need to be changed by the model user. The parameter *Climate* specifies the name of the subdirectory located within "data\climate\" that contains the actual climate data used by WEAP's Soil Moisture Model and MABIA module. In the current version of SacWAM there is only one directory, "Livneh," which contains the historical climate inputs derived from the Livneh et al. (2013) dataset as described in Sections 4.3 and 5.2.1. If another climate dataset is to be used, the model user should create a new subdirectory within "data\climate\" and enter the name of the new subdirectory into the *Climate* Key Assumption. In specifying the directory and subdirectory, the WEAP software uses a semi-colon (";") to signify a text string.





9.2 FixedRimResStorage

The Key Assumption *FixedRimResStorage* is used to select between constraining upper watershed reservoirs to operate to their historical levels and allowing the model to dynamically simulate reservoir storage driven by downstream demands and reservoir operational requirements (e.g., flood control). *FixedRimResStorage* can have a value of “0” or “1.” A value of “1” will result in the use of historical storage levels. This parameter was set to “1” during model calibration and validation exercises, but should normally be set equal to “0” to allow the model logic to operate the reservoirs.



FixedRimResStorage affects bounds on Top of Conservation and Top of Inactive parameters for reservoirs located in the upper watersheds:

- Black Butte Reservoir
- Camanche Reservoir
- Camp Far West
- Clear Lake
- East Park Reservoir
- Englebright Reservoir
- Folsom Lake
- Indian Valley Reservoir*
- Jenkinson Lake
- Keswick Reservoir
- Lake Berryessa
- Lake Natoma
- Lewiston Lake
- Los Vaqueros Reservoir
- New Bullards Bar
- New Hogan Reservoir
- Oroville Reservoir
- Pardee Reservoir
- Shasta Lake
- Stony Gorge Reservoir†
- Thermalito Afterbay
- Trinity Reservoir
- Whiskeytown Reservoir

*Top of Inactive only.

†Top of Conservation only.

FixedRimResStorage also affects the *Top of Buffer* parameter for the following reservoirs when reservoir operations are being dynamically simulated using model demands and logic:

- Folsom Lake
- Camp Far West
- Clear Lake
- New Hogan Reservoir
- Oroville Reservoir
- Camanche Reservoir
- Pardee Reservoir
- Lake Berryessa
- Shasta Lake
- Stony Gorge Reservoir
- Black Butte Reservoir
- New Bullards Bar

9.3 IFR and Simulate SWRCB IFRs

A set of WEAP IFR objects were created in SacWAM to allow SWRCB to study the effects of alternative flow requirements based on unimpaired flows. IFR objects were placed downstream from the major foothill reservoirs, on tributaries to the Sacramento River at their confluence with the Sacramento River, and at USGS and DWR gauge locations on the Sacramento River. These locations are listed in Table 9-1.

Table 9-1. Instream Flow Requirement Locations within SacWAM

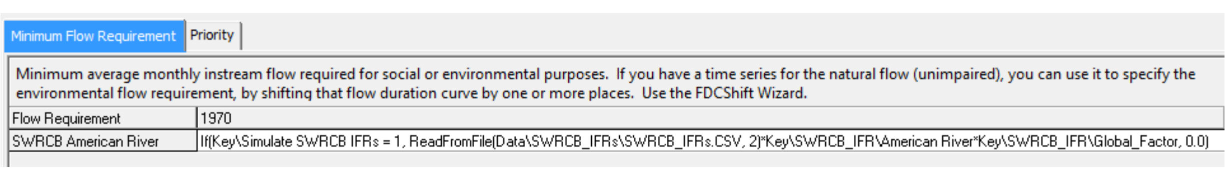
Reservoirs	Sacramento River Tributaries		Sacramento River	Other Valley Locations
Berryessa	American River	Cottonwood Creek	Above Bend Bridge	Delta outflow
Black Butte	Antelope Creek	Cow Creek	At Vina	
Camanche	Battle Creek	Deer Creek	At Hamilton City	
Camp Far West	Bear River	Feather River	At Ord Ferry	
Clear Lake	Big Chico Creek	Mill Creek	At Butte City	
Englebright	Butte Creek	Mokelumne River	At Colusa	
Folsom	Cache Creek	Putah Creek	Below Wilkins Slough	
New Hogan	Calaveras River	Stony Creek	At Knights Landing	
Oroville	Clear Creek	Thomes Creek	At Verona	
Shasta	Cosumnes River	Yuba River	At Freeport	
Trinity			At Rio Vista	

SacWAM was designed to run in an “unimpaired” mode in order to generate timeseries of unimpaired flows that can subsequently be used to create and test new flow requirements. In the unimpaired mode, all reservoirs, flow requirements, and diversions are inactive. To implement an unimpaired model run and generate unimpaired monthly timeseries for future use, the following steps should be followed:

1. Set the *Simulate Operations* key assumption to “0”.
2. Turn off all UDCs by navigating to *User Defined LP Constraints* in the data tree and unchecking the “Active?” box.
3. Run the model for the user-specified time period.
4. Export unimpaired flow timeseries from SacWAM results to a file called “SWRCB_IFRs.csv” using the “SWRCB IFR Flows” favorite.
5. Place the file “SWRCB_IFRs.csv” in the directory Data\SWRCB_IFRs\ in the WEAP area directory.

Once steps 1-5 are complete it will be possible to run the model with operations and the SWRCB IFRs active and explore the impacts of the new IFRs. To do so, set *Simulate Operations*=“1” and *Simulate SWRCB IFRs*=“1” and reactivate UDCs.

At runtime, SacWAM will now read timeseries data in the file “SWRCB_IFRs.csv” and use the data to determine IFRs. The model user has the option of multiplying the timeseries values by a parameter found in *Key Assumptions\SWRCB_IFR*, which can be used to scale the unimpaired flow by a time-varying amount. For example, the timeseries read from SWRCB_IFRs.csv by the IFR object located on the American River at its confluence with the Sacramento River can be scaled by the parameter *Key Assumptions\SWRCB_IFR\American River*. Additionally, all of these IFRs can be scaled globally by *Key Assumptions\SWRCB_IFR\Global_Factor*.



9.4 Simulate Hydrology

The Key Assumption *Simulate Hydrology* is used to select between DWR inflow timeseries and model simulation of hydrological processes using WEAP catchment objects. *Simulate Hydrology* can be assigned a value of “0” or “1.” A value of “1” activates the catchment objects.

Key Assumptions

These are user-defined variables that can be referenced elsewhere in your analysis. For monthly variation, use Month

Key Assumption	1970
Simulate Hydrology	0; 0=Use CalSim3 Inflow Time Series Data, 1=Use Upper Watershed Catchments to Simulate Hydrology

9.5 FixedUpperResStorage

The Key Assumption *FixedUpperResStorage* is used to choose between forcing the smaller reservoirs in the upper watersheds to constrain the Top of Inactive parameter to a static value or to use average monthly historical values. *FixedUpperResStorage* can have a value of “0” or “1.” A value of “1” will result in the use of historical storage levels. This variable was used during calibration and validation of the model and should normally be set at “0” to allow the model logic to operate the reservoirs.

Key Assumptions

These are user-defined variables that can be referenced elsewhere in your analysis. For monthly variation, use Monthly Time-Series Wizard.

Key Assumption	1922	Scale	Unit
FixedUpperResStorage	1; 0 = Set TOC and TOI to single values 1 = Fix TOC and TOI to average monthly storage		

- *FixedUpperResStorage* affects Top of Inactive storage for the following reservoirs
- Bowman Lake
- French Meadows
- Hell Hole
- Ice House
- Jackson Meadows Reservoir
- Lake Almanor
- Lake Combie
- Lake Fordyce
- Lake Spaulding
- Little Grass Valley Reservoir
- Loon Lake
- Merle Collins Reservoir
- Rollins Reservoir
- Scotts Flat Reservoir
- Sly Creek Reservoir
- Stony Gorge Reservoir
- Union Valley Reservoir

9.6 Use Water Board Vernalis Inflow

The Key Assumption *Use Water Board Vernalis Inflow* is used to select between two different flow timeseries for representing boundary inflows on the San Joaquin River at Vernalis. If a value of “0” is selected, a timeseries derived from CalSim II is used. If a value of “1” is selected, a timeseries developed during SWRCB’s Phase 1 process is used. For further details, see Section 7.2.2.2 in Chapter 7 on Other Assumptions.

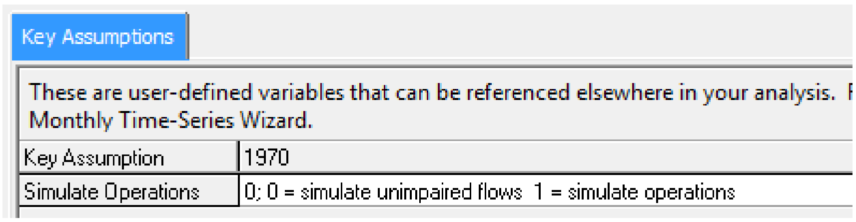
Key Assumptions

These are user-defined variables that can be referenced elsewhere in your analysis. For monthly variati

Key Assumption	1970
Use Water Board Vernalis Inflow	0; 0=Use CalSim2 Vernalis Inflow, 1=Use Water Board Vernalis Inflow

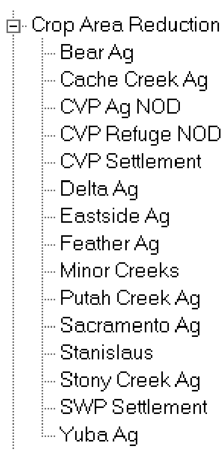
9.7 Simulate Operations

The Key Assumption *Simulate Operations* is used to select between two different simulation modes. If the variable is set to “0” then the model simulates unimpaired flows by switching off all reservoirs, IFRs, and transmission links. This option was provided so that the model can be used to generate unimpaired flow timeseries for the creation of IFRs (see Section 9.3). If this variable is set to “1” then all operations are simulated.

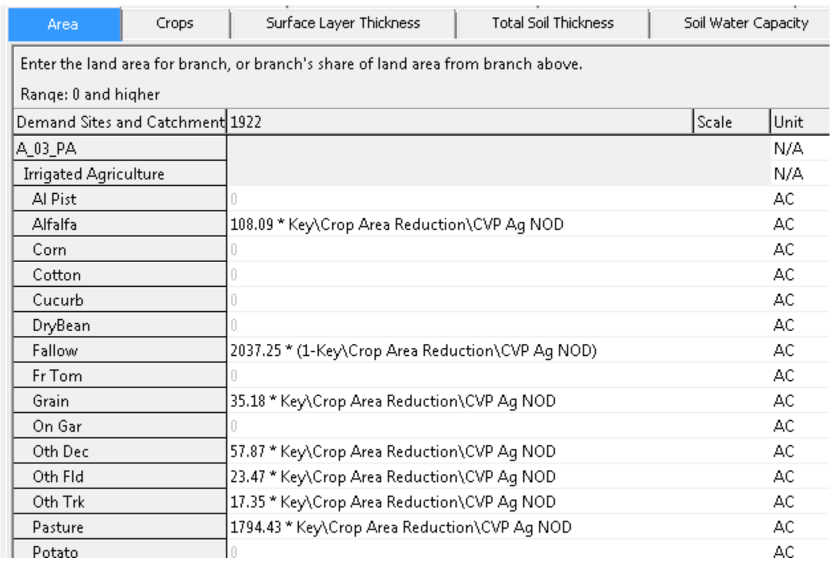


9.8 Crop Area Reduction

The Key Assumptions located under *Crop Area Reduction* are used as multiplicative factors to reduce the ICA. The factors should be assigned values between 0 and 1.



These factors are applied in the area expressions for the crops in each DU (below). The factor is multiplied by the area for each crop. The value of one minus the factor is multiplied by the total irrigated area of the DU in the Fallow crop class. The combination of these expressions reduces ICA by the factor and increases the fallow area by an equivalent amount, thereby maintaining the same land area. Different DUs are affected by different reduction factors as indicated in Table 9-2.



Area | Crops | Surface Layer Thickness | Total Soil Thickness | Soil Water Capacity

Enter the land area for branch, or branch's share of land area from branch above.

Range: 0 and higher

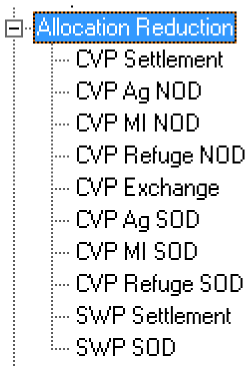
Demand Sites and Catchment	1922	Scale	Unit
A_03_PA			N/A
Irrigated Agriculture			N/A
Al Pist	0		AC
Alfalfa	108.09 * Key\Crop Area Reduction\CVP Ag NOD		AC
Corn	0		AC
Cotton	0		AC
Cucurb	0		AC
DryBean	0		AC
Fallow	2037.25 * (1-Key\Crop Area Reduction\CVP Ag NOD)		AC
Fr Tom	0		AC
Grain	35.18 * Key\Crop Area Reduction\CVP Ag NOD		AC
On Gar	0		AC
Oth Dec	57.87 * Key\Crop Area Reduction\CVP Ag NOD		AC
Oth Fld	23.47 * Key\Crop Area Reduction\CVP Ag NOD		AC
Oth Trk	17.35 * Key\Crop Area Reduction\CVP Ag NOD		AC
Pasture	1794.43 * Key\Crop Area Reduction\CVP Ag NOD		AC
Potato	0		AC

Table 9-2. Demand Unit Crop Area Reduction Factors and Associated Demand Units

Reduction Factor	DU Prefix	Affected Demand Units
Bear Ag	A_	23_NA, 24_NA1, 24_NA2, 24_NA3
Cache Creek Ag	A_	20_25_NA1
CVP Ag NOD	A_	02_PA, 03_PA, 04_06_PA1, 04_06_PA2, 07_PA, 08_PA, 16_PA, 21_PA
CVP Settlement	A_	02_SA, 03_SA, 08_SA1, 08_SA2, 08_SA3, 09_SA1, 09_SA2, 18_19_SA, 21_SA, 22_SA1
Delta Ag	A_	50_NA1, 50_NA2, 50_NA3, 50_NA4, 50_NA5, 50_NA6, 50_NA7
Eastside Ag	A_	60N_NA1, 60N_NA3, 60N_NA4, 60N_NA5, 60S_PA
Feather Ag	A_	12_13_NA
Minor Creeks	A_	02_NA, 03_NA, 04_06_NA, 05_NA, 10_NA
Putah Creek Ag	A_	20_25_NA2, 20_25_PA, SIDSH
Sacramento Ag	A_	08_NA, 09_NA, 11_NA, 16_NA, 17_NA, 18_19_NA, 21_NA, 22_NA
Stanislaus	A_	61N_NA2, 61N_NA3, 61N_PA
Stony Creek Ag	A_	04_06_PA3
SWP Settlement	A_	11_SA1, 11_SA2, 11_SA3, 11_SA4, 12_13_SA, 14_15N_SA, 15S_SA, 16_SA, 17_SA, 22_SA2
Yuba Ag	A_	14_15N_NA2, 14_15N_NA3, 15S_NA
CVP Refuge NOD	R_	None

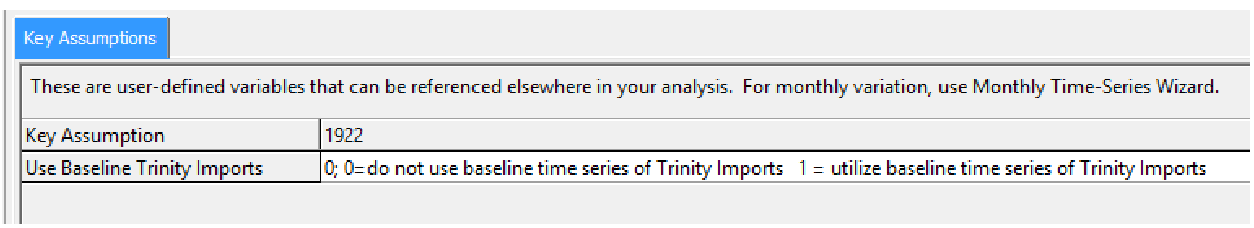
9.9 Allocation Reduction

The Key Assumptions located under *Allocation Reduction* are used as multiplicative factors to reduce allocations beyond the reduction that occurs through the logic described in Chapter 7. There are a total of 10 different allocation types that can be adjusted using these Key Assumptions (see below). These Allocation Reduction factors should have values between 0 and 1.



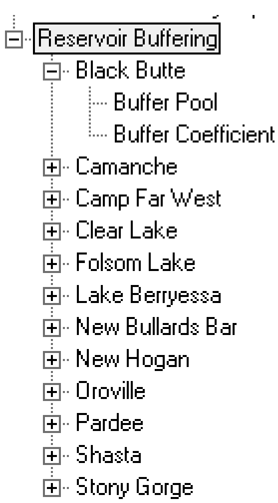
9.10 Use Baseline Trinity Imports

The *Use Baseline Trinity Imports* Key Assumption is used to specify whether the model should use a baseline timeseries of Trinity River imports through the Clear Creek Tunnel or dynamically determine these imports based on storage conditions. If a value of “1” is entered, a monthly timeseries of flows through the Clear Creek Tunnel will be read from Data\Diversions\SACVAL_ClearCreekTunnel_DiversionFlows.csv. If a value of “0” is entered, the model will simulate Clear Creek Tunnel flows using the logic described in Chapter 7.

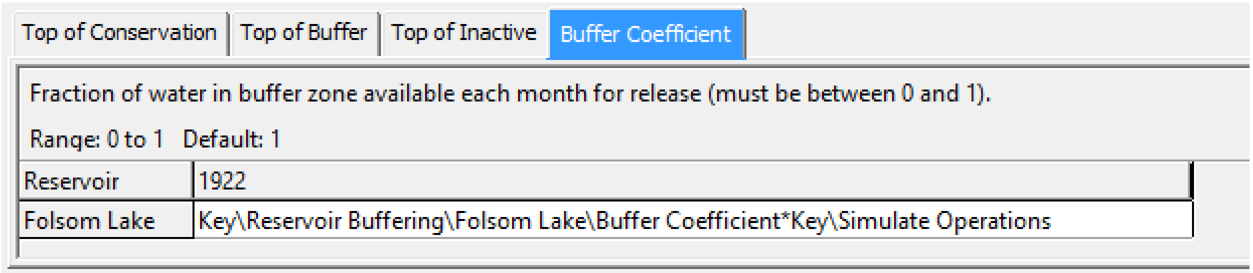


9.11 Reservoir Buffering

The Key Assumptions under Reservoir Buffering can be used to set the buffer pool volume and buffer coefficient for upper watershed reservoirs. These Key Assumptions were provided to simplify the specification of buffering parameters for reservoirs of interest to SWRCB.



These Key Assumptions are, in turn, read into the expressions for Top of Buffer and Buffer Coefficient parameters in the reservoir interface, as shown in the example below.



9.12 Constrain Unimpaired Run GW Pumping

The Key Assumption *Constrain Unimpaired Run GW Pumping* affects model access to groundwater. A value of “1” adds groundwater pumping limits; a value of “0” does not impose groundwater pumping limits in the model. For more details on model limits to groundwater pumping, see the Groundwater Pumping discussion in Section 3.3.

9.13 Units

Different data sources use different units. The Key Assumptions under *Units* contain conversion factors for TAF/month to cfs (*TAFmonth2CFS*), inches to millimeters (*in2mm*), and cfs to cubic meters per month (*convertcfstom3*).

Chapter 10 Model Calibration

SacWAM was calibrated in a multi-step process that covered the upper watersheds, the Sacramento Valley floor and CVP/SWP project operations. The first step was to calibrate the rainfall runoff processes in the catchments located upstream from the valley rim reservoirs as these calculations are independent of all other processes in the model. This involved tuning the Soil Moisture method hydrological parameters in the catchments until simulated and observed historical flows matched within an acceptable degree of tolerance. This process is described in Appendix A. The next step was to focus on processes occurring on the Sacramento Valley floor. Here, the initial focus was on surface water diversions as they are largely a function of evapotranspiration and irrigation management parameters. Simulated evapotranspiration values were compared to values from DWR's CUP model. Simulated diversions were compared to historical observations and adjustments to irrigation management parameters were made as needed. Following that, an iterative process was employed in calibrating the rainfall runoff processes and the stream-aquifer interactions to historical stream flow observations and simulated stream-aquifer interaction flows from the C2VSim groundwater model. These processes were calibrated in an iterative fashion due to the interactions between rainfall runoff processes and stream-aquifer interactions. Finally, operations logic in the Other Assumptions and User Defined LP Constraints were refined so that CVP and SWP operations closely matched the CalSim II model. The valley floor calibration is described in Appendix B.

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Chapter 11 Model Use and Limitations

Over the last decade, computer simulation model have been widely used in California to support a diverse range of policy and regulatory decisions, planning processes, and environmental review. With expanding use of models, it becomes increasingly important to identify the purpose for which the model has been developed, appropriate model use, model limitations, and guide the interpretation of model results. This chapter briefly reviews these aspects of SacWAM.

11.1 Model Objective

SacWAM has been developed by the State Water Board to support update of the 2006 Bay-Delta Plan. The model may be used to inform the following types of analyses as part of the agency's assessment of potential alternative regulatory requirements:

- Estimates of flow conditions under a range of alternative regulatory requirements.
- Estimates of changes in water diversions for use in an evaluation of the impacts of alternative regulatory requirements on agricultural resources, water suppliers, and groundwater.
- Estimates of changes in reservoir storage for use in an analysis of the impacts of alternative regulatory requirements on hydropower generation, recreation, and fisheries.
- To inform other analyses or models, such as Delta hydrodynamics, Delta water quality, water temperature, economic, and fisheries benefits models.

It is intended that SacWAM be transparent, easy to use, and freely available. The WEAP software and its interactive GUI was designed to facilitate a shared model vision. However, the SacWAM application is complex, highly detailed, and requires the model user to be familiar with both system operations modeling and California water. Additionally, SacWAM requires a significant investment of time to become familiar with the schematic, properties of objects, and user-defined variables and constraints. This imposes barriers to widespread model use.

The WEAP software is freely available to California water agencies. Before the development of SacWAM, all WEAP applications used a free MIP solver. However, given the unprecedented size and complexity of SacWAM, it was necessary to substitute the free solver with a commercial product (XA) to decrease run time and eliminate failures to solve. [22] A single XA license costs between $1,000 and $2,000, which again imposes barriers to widespread use of the model. Full model results are large, of the order of 4 GB, and so cannot easily be distributed with SacWAM.

11.2 Appropriate Use of Model

SacWAM should be used in a comparative manner in which model results for a particular alternative are compared to a base simulation. In the comparative analysis, differences in certain factors, such as

[22] Solution time for a 10-year simulation period with the free solver is approximately 3 hours. In a test run, the free solver was forced to relax constraints in 14 months over the 10 years to find a feasible solution. Model run time with the XA solver for an 88-year period of simulation is less than 1.5 hours with no relaxation of constraints.

deliveries or reservoir storage levels, are analyzed to determine the impact of the alternative. SacWAM should not be used in an absolute, stand-alone analysis in which model results are used to predict an outcome.

SacWAM results are believed to be more reliable in a comparative study than an absolute study. All of the assumptions are the same for baseline and alternative model runs, except the action itself, and the focus of the analysis is the differences in the results. Model errors, introduced through necessary simplification of the real world and which render absolute analysis unreliable, are assumed to be independent of the scenario being considered, so that these errors will largely cancel out in a comparative analysis.

11.3 Interpretation of Model Results

SacWAM is a long-term planning model developed for planning analysis. It is not intended to be used to support real-time reservoir operations and water delivery decisions. Although SacWAM uses historical hydrology to represent a reasonable range of water supply conditions, SacWAM does not simulate historical water conditions. Simulated results for a particular year will not correspond to historical storage and flows and do not provide information about historical events. Model results are best interpreted using various statistical measures such as long-term or year-type averages.

11.3.1 Temporal Resolution

SacWAM uses a monthly time step for all operational decisions and for routing water through the SacWAM schematic. Operational requirements that affect day-to-day management of water infrastructure are not included in the model, such as hourly and daily reservoir flow ramping rate criteria. Average monthly flows may not accurately represent operations that respond to daily variability in water conditions, such as reservoir flood control operations. Therefore, disaggregation of monthly model results to finer time scales should be undertaken with caution and may not be an appropriate use of the model.

11.3.2 Spatial Resolution

SacWAM is built on a very detailed spatial representation of the water supply network in the Sacramento Valley and Delta. However, the model necessarily simplifies the depiction of streamflows by aggregating surface water diversions, return flows, surface runoff, and groundwater inflows to the stream network. Only downstream from these points of aggregation will SacWAM accurately simulate streamflows.

11.3.3 Drought Conditions

SacWAM operational decisions are based on a set of predefined rules that represent existing regulations, contract agreements, and obligations. The model has no capability to dynamically adjust these rules based on extreme hydrologic events such as prolonged drought. For example, the model does not represent the Temporary Urgent Change Petitions (TUCP) that were submitted by DWR and Reclamation to the State Water Board in 2014 and 2015. The TUCP resulted in temporary changes to Delta Cross Channel operations, Delta outflow requirements, and Delta export limits. Similarly, in 2014, drought conditions resulted in Reclamation meeting San Joaquin River exchange contractor water demands with a mix of Delta and San Joaquin River sources. Currently, SacWAM does not have the ability to represent this type of operational change from a standard procedure. This simplification results in excessive water demands on SWP/CVP reservoirs and excessive reservoir draw down in individual dry years. Model results for drought conditions should be presented in terms of water year type averages and operations for specific dry year such as 1924, 1977, and 1991 should not be the focus of the analysis.

11.3.4 Time Frame

The SacWAM simulation represents "existing conditions", or approximately 2010, for land use, population, infrastructure, and regulatory environment. Currently, no model version has been developed for future (No Project/No Action) conditions, as is typically required for environmental review and documentation.

11.4 Computational Methods

11.4.1 Objective Function

WEAP uses a MIP solver to solve a series of equations that seek to maximize an objective function that will best allocate water resources according to a user-defined set of delivery, flow, and storage priorities (weights). This set of equations also includes physical and operational constraints of the system as defined by the user.

The WEAP solution algorithm facilitates the development of the objective function through simply classifying a hierarchy of priorities, which are met sequentially. However, this approach prevents trade-offs between high priority objectives and those of lower priorities. It also limits model functionality and flexibility, for example, the model user cannot use negative weights to discourage certain actions.

11.4.2 Iterative Solution Technique

The MIP solver does not optimize across multiple time steps or across multiple objectives. Rather, the MIP solver runs iteratively within each time step to allocate current water resources within the system, priority by priority. Successive solution of priorities and preferences are known as allocation orders. The WEAP algorithm moves sequentially through priority levels 1 through priority 99 before moving to the next time step and through supply preferences within a priority. Objectives achieved for a given allocation order are enforced as constraints in all successive priorities and solutions.

A significant amount of model development time was spent eliminating "relaxation of constraint" errors caused by numerical rounding and the iterative WEAP solution technique. These problems were resolved by modifying the WEAP software to allow injection of small amounts of water to overcome model infeasibilities. The amounts injected are typically much less than 1 cfs, but in a new run the model user must check that amounts injected are not significant.

11.4.3 Flexibility

WEAP has no ability to refer to values of decision variables established in previous allocation orders within the same time step. Regulations that require layering of requirements based on the previous state of the system (within the same time step) cannot easily be modeled. For example, simulation of

SWP use of unused Federal share of water under COA requires some model ‘tricks’ that make model operations less transparent.

Typically, user-defined constraints are active through all allocation orders. For example, Delta outflow requirements are imposed as a model constraint when determining allocation decisions regarding local operations in tributary watersheds. Additionally, priorities are only active in one allocation order, so that storage in a particular reservoir is only valued in one allocation order. Results from individual allocation orders prior to the final solution may not be meaningful.

11.4.4 Robustness

Model development has focused on the base simulation of existing conditions. Less effort has been focused on testing the model over a wide range of alternative scenarios or conducting a sensitivity analysis to check that the model correctly responds to different changes in regulatory requirements. However, the State Water Board has worked with DWR staff to validate SacWAM using a comparative analysis of a 50 percent unimpaired flow alternative to existing conditions.

11.5 Model Calibration and Validation

SacWAM is a monthly accounting tool. Some of its routines are physically-based and can be calibrated to observed data, e.g., the MABIA root-zone daily soil moisture simulation. However, many aspects of SacWAM are not physically based, being simplifications of complex operating criteria and regulations. These management aspects of the model cannot be calibrated. Instead SacWAM simulation has been validated through comparison with CalSim II, a management or planning model for the SWP and CVP.

11.6 Climate Change

Climate change is a key consideration in planning for the State’s water management. California’s aging water infrastructure was designed and built based on an analysis of historical hydrology; past weather patterns have long been assumed to be representative of future conditions. However, as climate change continues to affect California, past hydrology is no longer a reliable guide to the future.

SacWAM uses a historical sequence of 88-years inflow hydrology and historical climate data to simulate both water supply and water demands. Currently, no climate change scenarios have been developed for the model. Additionally, no adaptive management actions or model code have been developed to help offset climate change effects. For example, reservoir flood space reservations could be adjusted in response to changing seasonal inflow patterns.

SacWAM offers two modes of simulation with respect to the upper watersheds: use of historical unimpaired inflows that are inputs to the model; and climate driven runoff simulated using WEAP’s catchment objects. Historical streamflow records are usually incomplete and unimpaired inflows input to the model are often derived using statistical techniques. Inflows have been developed assuming stationarity over the historical period and assuming statistical relationships between (unimpaired) streamflows are constant. This assumption of stationarity is not appropriate when there has been significant land use change in the upper watersheds or when climate change has occurred. The effects of climate change can be simulated through the use of the WEAP catchment objects as this effectively changes the inputs into the model from streamflows to climatic inputs such as precipitation, temperature, wind speed, and humidity.

11.7 Sea-Level Rise

Sea levels have increased steadily over the past century and are projected to continue to increase throughout this century. Sea level rise will affect the eastward movement of salt into the Delta, requiring additional freshwater Delta outflow to repel salinity and meet existing Delta water quality standards. SacWAM uses an ANN embedded within the model to translate water quality standards to a Delta outflow requirement. The ANN was developed by DWR for use in its planning studies and seeks to emulate flow-salinity relationships derived from DWR's one-dimensional hydrodynamic and water quality model, DSM2. DWR has developed several versions of ANN that are appropriate for representing existing conditions, 15 cm sea-level rise (~2025 conditions), and 45 cm sea-level rise (~2060 conditions).

Currently, SacWAM has only been linked to the ANN for existing conditions. Additionally, no operational logic has been developed for potential adaptive management actions to address future Delta conditions affected by sea-level rise.

11.8 Model Limitations

This section discusses limitations of particular aspects of SacWAM.

11.8.1 Watershed Hydrology

WEAP uses a one-dimensional lumped parameter hydrologic model to estimate monthly runoff, baseflow, ET, groundwater recharge, and soil water storage. The SacWAM domain is divided into upper watersheds and valley floor. The upper watersheds are further divided into sub-catchments based on elevation so that the model can simulate snow accumulation and snowmelt processes. However, elevation bands are coarse, 500 meters. Refinement of these elevation bands and additional calibration would improve simulated flows derived by climate data (precipitation and temperature).

11.8.1 Water Supply Forecasts

SacWAM uses a mix of perfect foresight and forecasts to estimate water supply conditions. For example, water supply indices and water years types that control many regulatory flow requirements may either be set equal to historical values, or be dynamically forecasted based on simulated winter snowpack and regression analysis that associates snowpack within each of the watersheds to future runoff. SWP and CVP contract allocations are based on current month reservoir levels and future inflows determined using 90 percent or 99 percent exceedence forecasts. However, simulation of local agency operations are typically based on perfect foresight of water supply conditions.

11.8.2 Upstream Watershed Operations

SacWAM implements a very simple approach in simulating most of the reservoirs in the upper watersheds of the Sierra Nevada Mountains. The top of the conservation pool is set equal to average monthly historical storage. In wet years, simulated storage will follow this rule curve. Under drier conditions, reservoir storage will fall to lower values. Further refinement is needed to more accurately simulate these reservoirs, which are typically operated for hydropower.

11.8.3 Sacramento - San Joaquin Delta

The complexity of Delta channel flows and Delta salinity cannot be included in a flow-based accounting model, such as SacWAM.

SacWAM does not simulate Delta water quality conditions that drive operation of Contra Costa WD's Los Vaqueros Project.

In the default set-up, SacWAM uses values of Delta channel accretions and depletions that were developed by DWR for use in their planning models. While this maintains consistency with past analysis, DWR has recognized that that their estimates of channel depletions may underestimate Delta consumptive use because of low estimates of crop evapotranspiration.

11.8.4 San Joaquin River at Vernalis

San Joaquin River flows at Vernalis and associated water quality are inputs to the model and must be derived from other modeling activities. SacWAM contains no dynamic links between San Joaquin River conditions at the Delta boundary and other parts of the model. San Joaquin River flows and salinity are treated as being independent of SWP and CVP water deliveries to the San Joaquin Valley, which are dynamically determined at run-time.

11.8.5 Groundwater

Ten groundwater basins are simulated in SacWAM using the WEAP groundwater objects. Parameters governing the stream-groundwater interaction were calibrated to match results from DWR's distributed groundwater model of the Central Valley, C2VSim. Stream-groundwater interaction is simulated as a linear function of streamflow and may fluctuate in direction, but is independent of groundwater levels. Thus, surface water flows are independent of the state of the underlying aquifer.

Simulation of groundwater overdraft in SacWAM may not be realistic as there is no feedback mechanism to limit groundwater outflows as elevations fall (or conversely as elevations rise).

11.8.1 Hydropower Operations

SacWAM does not simulate hydropower operations or power generation. Reservoirs with associated hydropower facilities are either simulated using a fixed rule curve, or for multi-purpose reservoirs it is assumed that hydropower generation is secondary to water supply objectives.

11.8.2 Water Temperature Objectives

SWP and CVP operations are often dictated by water temperature considerations. For example, the NMFS 2009 BiOp specifies actions to protect fall-, winter-, and spring-run chinook through cold water pool management of Lake Shasta. The BiOp establishes water temperature and compliance points at various locations on the Sacramento River above Bend Bridge and on Clear Creek (Action Suite 1.2). The BiOp also establishes objectives for end-of-September carryover storage in Lake Shasta. Long-term performance measures are specified in terms of exceedence.

SacWAM contains no specific actions to meet the requirements of Action Suite 1.2 contained in the NMFS 2009 BiOp. SacWAM cannot operate to meet exceedence-based performance criteria. SacWAM has no ability to translate water temperature based objectives in to flow equivalents. The model specifies flow requirements below Keswick based on Reclamation modeling of CVPIA 3406(b)2 actions undertaken for the 2008 OCAP for the CVP and SWP. Post-processing of SacWAM results is required to assess exceedence-based metrics. Additional analysis using a water temperature model is required to assess water temperatures resulting from SacWAM actions. In the future, this type of analysis may result in refinement of current flow schedules implemented in SacWAM.

11.8.3 Biological Objectives

Regulatory requirements that were established to protect threatened and endangered fish species and their habitats are often triggered by metrics other than flow and storage. For example, the 2008 USFWS RPAs may be triggered by water temperatures, turbidity, spawning, migration, salvage, and results of fish surveys. These triggers cannot be dynamically implemented in SacWAM, and the model must use either flow surrogates or preset schedules of actions. For example, OMR reverse flow criteria, as simulated in SacWAM, will only approximate real-time decisions made by the fishery management agencies.

11.8.4 Water Rights

Currently, the SacWAM portrayal of water rights is limited to major water agencies and water districts that divert from the Sacramento River and its major tributaries.

11.8.5 Contract Allocations

The procedures used in SacWAM to compute allocations for CVP and SWP include lookup tables that estimate the amount of the available water supply that can be used for delivery and/or carryover storage. These lookup tables are referred to as the WSI-DI curves. The curves are developed through an iterative process wherein they are updated with each successive model run until the model is able to deliver the allotted allocation with no delivery deficits. The WSI-DI relationship depends on three key features of the modeled system: hydrology; water supply infrastructure; and the regulatory environment. If significant changes are applied to any of these three model elements, then new WSI-DI curves should be developed to prevent over or under allocation to SWP and CVP contractors. Currently, SacWAM has no automated procedures to develop new WSI:DI curves.

11.8.6 Water Transfers

Water transfers are currently not simulated in SacWAM

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